Situating sustainable chemistry in teaching and learning with Systems Thinking

Seamus Delaney

STAV VCE Chemistry teacher workshop

Elements of Sustainable Chemistry (ESC) research hub

Deakin STEME group, Deakin University

Elements of Sustainable Chemistry (ESC)

Acknowledgements

Madeleine Schultz (School of Life & Enviro Sci, Deakin)

Peter Mahaffy (Kings University, Alberta)
Tom Holme (Iowa State University)
Mary-Kay Orgill (University of Nevada, Las Vegas)

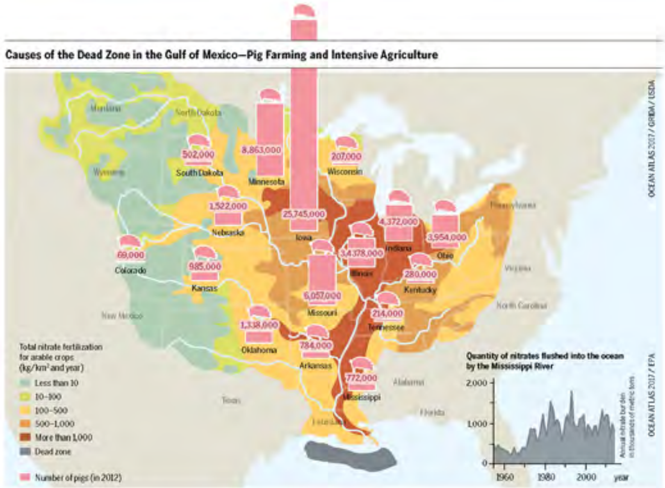
Deakin Science and Society Network (SSN) ($)
Australian National Commission for UNESCO ($$)

New resources website
www.eschemistry.org

2

Chemistry and sustainable development

'Peak phosphorus'



3

Chemistry and sustainable development

Plastics, fertilisers, smog, food waste, textiles are all examples of <u>systemic failure</u>

A System…

- has multiple scales and boundary conditions
- has parts that must be present for a system to carry out its purpose optimally
- attempts to maintain stability through feedback
- Has a purpose
    - What was the *purpose* of these systems?

4

Activity 1 – Utilisation of elements

Compare it to an issue *not that long ago…*

Discuss the element lead including human activity related to lead

Think about the physical and chemical properties of lead that make it useful for people

5

Activity 1 – Utilisation of elements

Discuss the element lead including human activity related to lead…

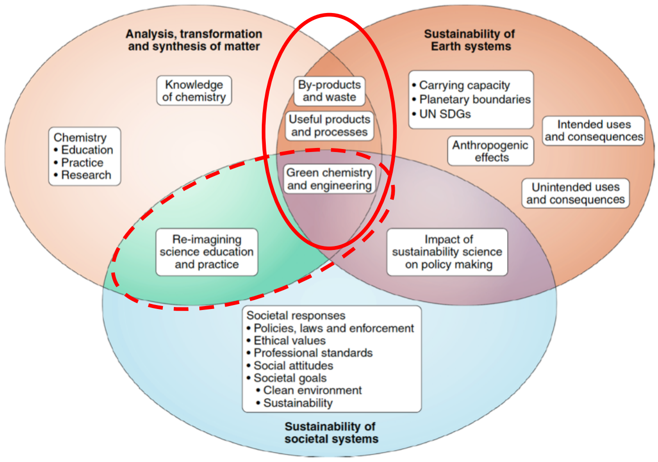
- Uses of lead by Romans
- Sweetness due to chemical reaction forming acetate salt
- Toxicity already recognised 2000 years ago
- Modern uses of lead
- Paint
- Petrol
- Toxicity known for a long time before it was outlawed

Stimulate student discussion

Responsible use of science

6

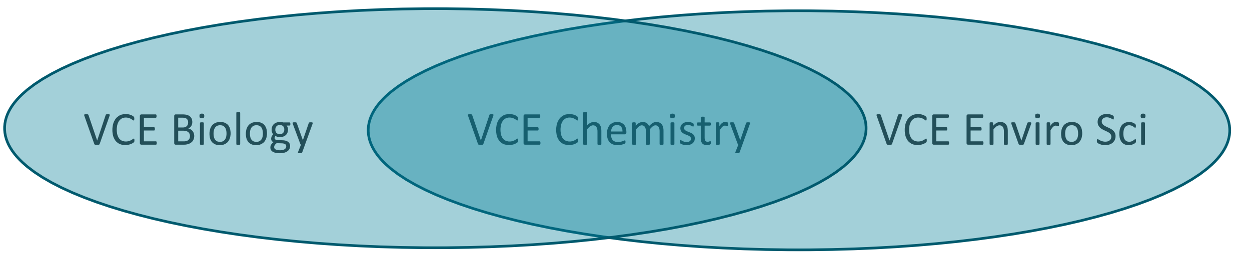
Re-positioning chemistry as the sustainability science



Mahaffy, P. G., Matlin, S. A., Holme, T. A., & MacKellar, J. (2019). Systems thinking for education about the molecular basis of sustainability. *Nature Sustainability, 2*(5), 362-370. doi: 10.1038/s41893-019-0285-3

7

Re-positioning chemistry as the sustainability science



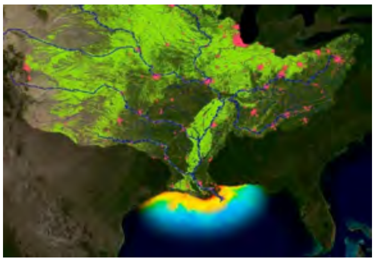
- Biological systems
- Cells, conditions to maintain living things

- Transformation, synthesis and analysis of matter
- Explaining chemical basis for systems

- Earth Systems
- Sustainability policy

8

Traditional teaching approaches in Chemistry



Facts are presented in isolation

Students are introduced to content within separate topics

Example: synthesis of ammonia

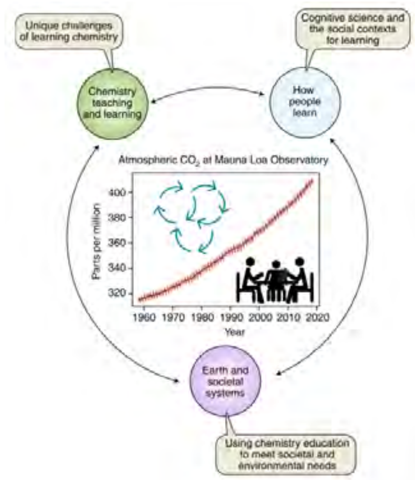
$$N_2 + 3H_2 \longrightarrow 2NH_3$$

Used as an example to teach:

- Balancing equations
- Equilibrium
- Gibbs free energy, entropy
- Catalysis
- History, importance in WWII sometimes mentioned

9

Systems Thinking in Chemistry Education (STICE)



IUPAC Task Group (2017 – Present)

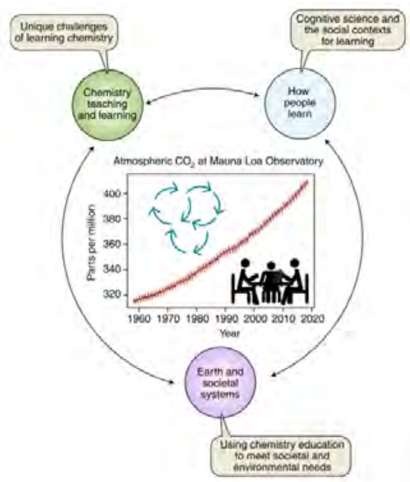
An approach to addressing problems that incorporates the complexity of a whole system in a holistic manner

- Includes intended and unintended consequences
- Incorporates critical thinking
- Incorporates scientific investigation and design thinking by emphasising innovation
- Pedagogical precedent in Biology, Engineering, Public health

Mahaffy, P. G., Matlin, S. A., Holme, T. A., & MacKellar, J. (2019). Systems thinking for education about the molecular basis of sustainability. *Nature Sustainability, 2*(5), 362-370.

10

Systems Thinking in Chemistry Education (STICE)



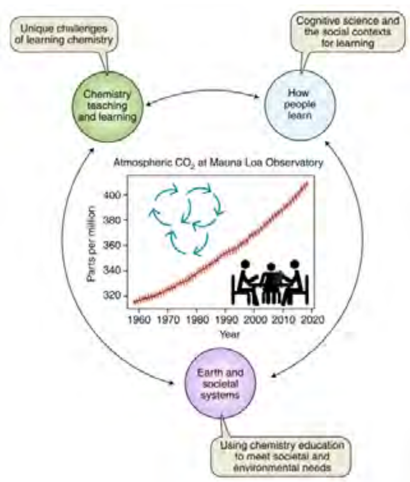
IUPAC Task Group (2017 – Present)

An approach to addressing problems that incorporates the complexity of a whole system in a holistic manner

- Situate chemistry content in the real world context
- Reduce reductionist teaching in chemistry
- Re-position Chemistry to consider relationship between by-products/waste and useful products and processes

11 Mahaffy, P. G., Matlin, S. A., Holme, T. A., & MacKellar, J. (2019). Systems thinking for education about the molecular basis of sustainability. *Nature Sustainability, 2*(5), 362-370.

Systems Thinking in Chemistry Education (STICE)



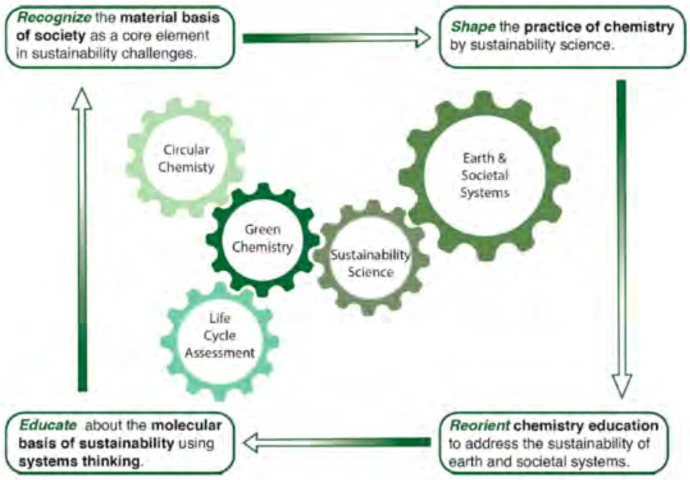
IUPAC Task Group (2017 – Present)

An approach to addressing problems that incorporates the complexity of a whole system in a holistic manner

> "…the molecular basis for sustainability"

12 Mahaffy, P. G., Matlin, S. A., Holme, T. A., & MacKellar, J. (2019). Systems thinking for education about the molecular basis of sustainability. *Nature Sustainability, 2*(5), 362-370.

Systems Thinking in Chemistry Education (STICE)



Mahaffy, P. G., Matlin, S. A., Whalen, J.M. & Holme, T. A. (2019). Integrating the Molecular Basis of Sustainability into General Chemistry trough Systems Thinking. *Journal of Chemical Education*. Doi: 10.1021/acs.jchemed.9b00390

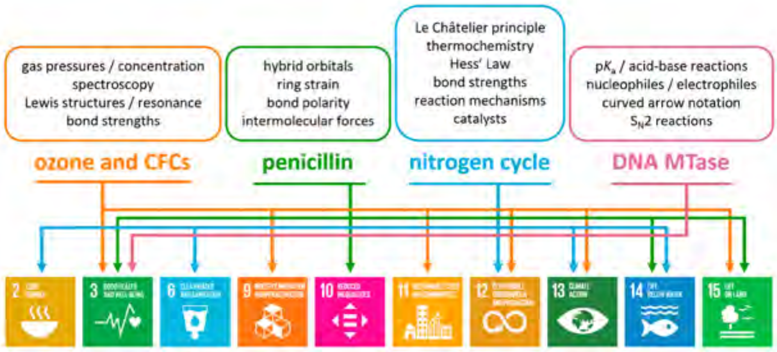
Chemistry and sustainable development

Connecting Chemistry with the UN Global Goals for Sustainable Development (SDGs)

https://sustainabledevelopment.un.org/

Chemistry and sustainable development

Connecting Chemistry with the UN Global Goals for Sustainable Development (SDGs)

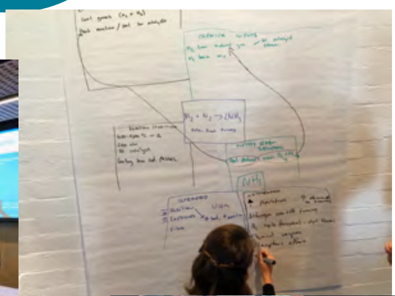


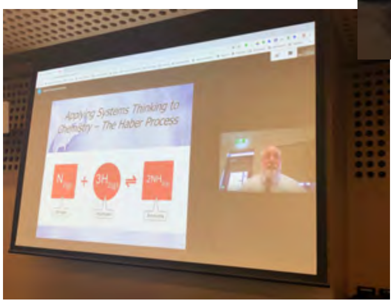
Petillion, R. J., Freeman, T. K. & McNeil, W. S. (2019) United Nations Sustainable Development Goals as a Thematic Framework for an Introductory Chemistry Curriculum. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00307

15

STICE workshops at Deakin - 2019

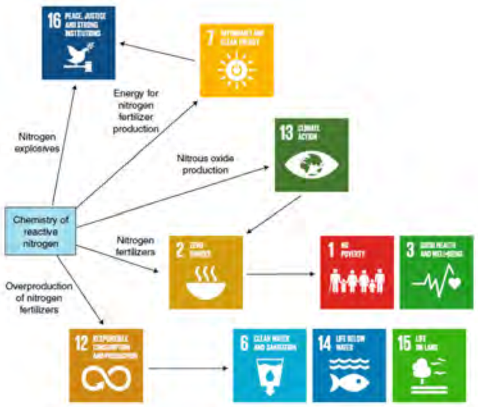
Interdisciplinary - secondary teachers (Chem Ed) and researchers (Science, Engineering) workshops

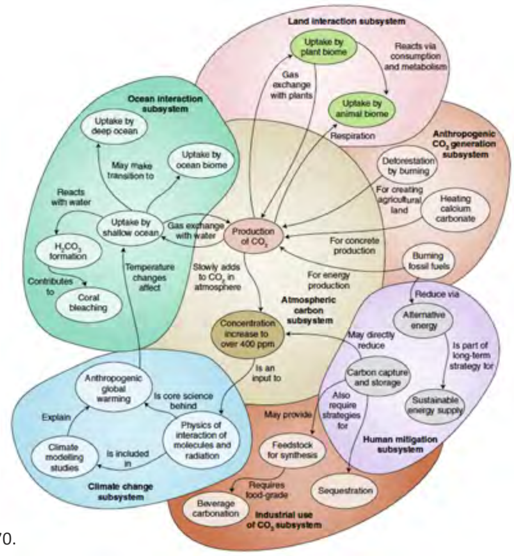




16

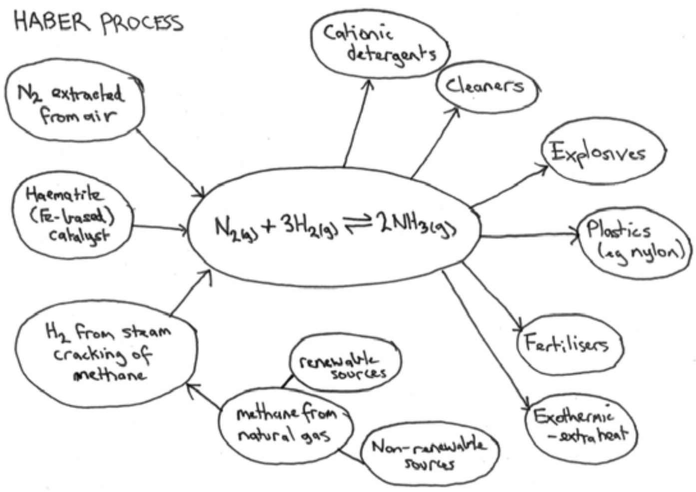
Evaluating systems thinking - Systems Maps





17 Mahaffy, P. G., Matlin, S. A., Holme, T. A., & MacKellar, J. (2019). Systems thinking for education about the molecular basis of sustainability. *Nature Sustainability, 2*(5), 362-370.

Evaluating systems thinking - Systems Maps

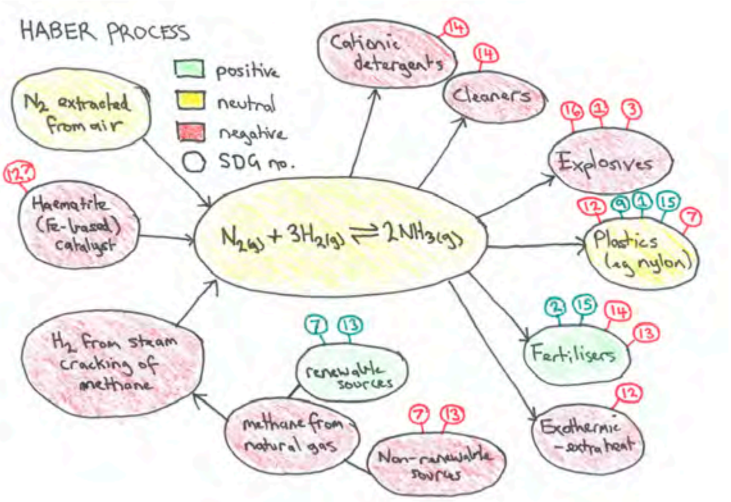


Teacher action research and student impact evaluation

- **Systems mapping** to situate knowledge of chemistry within everyday knowledge of students

18 Eaton, A. C., Delaney, S., & Schultz, M. (2019). Situating Sustainable Development within Secondary Chemistry Education via Systems Thinking: A Depth Study Approach. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00266

Evaluating systems thinking - Systems Maps



Teacher action research and student impact evaluation

- **Systems mapping** to situate the sustainable development goals (SDGs) within their learning of chemistry

19 Eaton, A. C., Delaney, S., & Schultz, M. (2019). Situating Sustainable Development within Secondary Chemistry Education via Systems Thinking: A Depth Study Approach. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00266

Evaluating systems thinking - Systems Maps

The ”central learning outcome” of chemistry…

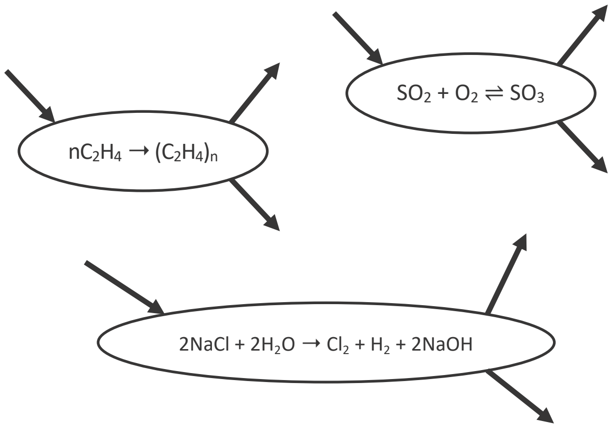
“Chemicals have benefits and hazards, and ***these must considered together***” (p. 499)

”… pedagogically essential to consider that the practice of chemistry has both negative and positive impacts” (p. 499)

(Holme and Hutchison, 2018)

20 Eaton, A. C., Delaney, S., & Schultz, M. (2019). Situating Sustainable Development within Secondary Chemistry Education via Systems Thinking: A Depth Study Approach. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00266

Activity 2 – Systems maps



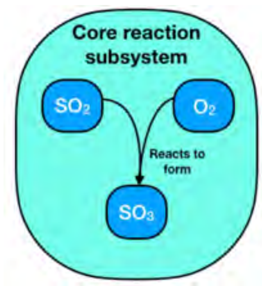
1. Pick a chemical process
2. What are your inputs? Mass inputs? Energy inputs?
   - And their inputs?
3. What are your outputs…
   - Intended uses?
   - Unintended consequences?
4. Look at the SDGs, attach numbers to each of your inputs and outputs
   - Positive influence?
   - Negative influence?
5. So what does this tell us about the sustainability of this chemical process?

21

Systems-oriented Concept Mapping Extension (SOCME)

Systems-oriented Concept Mapping Extension (SOCME)

- Similar to concept maps, with a key distinction.
- The goal is to explicitly incorporate the **knowledge of boundaries** on the stuff you are interested in (which is going to be a system)
- Visualise the complexity and interactions across parts of a system, with minimal prose.



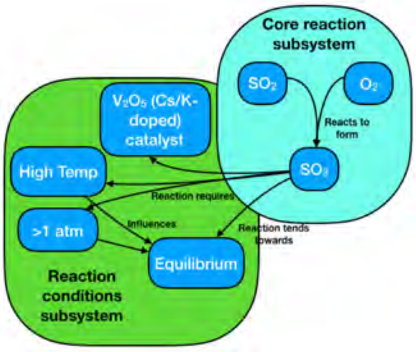
Start with the 'the core'

- Consider the systems inputs, and its outputs (consequences)
- Then….what ask what happens as we change the boundaries on the system

Systems-oriented Concept Mapping Extension (SOCME)

Connecting with current content

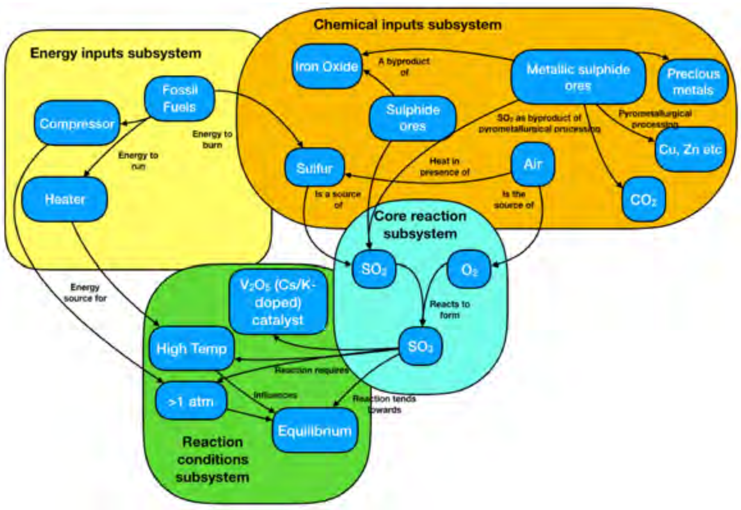
- Add in subsystems
  - Where the starting materials come from
  - Energy involved in production
  - Intended and unintended consequences of the use of the product
  - What happens to the product when it is no longer used



Systems-oriented Concept Mapping Extension (SOCME)

Connecting with current content

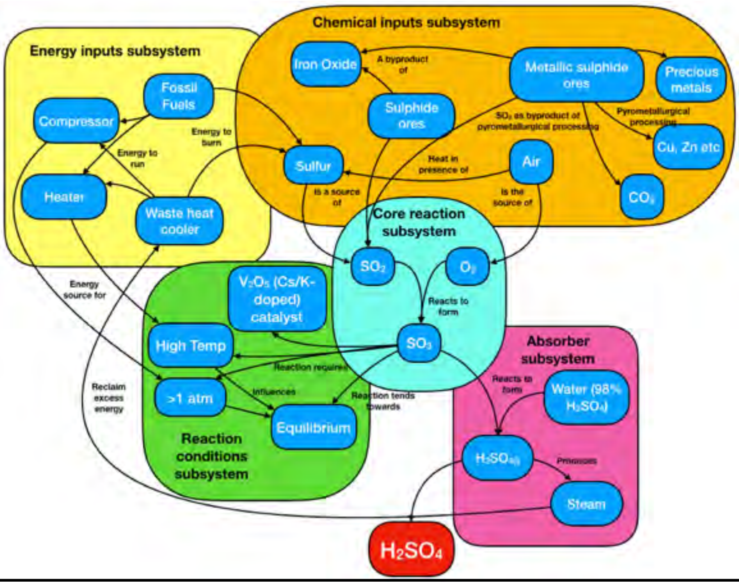
- Add in subsystems
  - Where the starting materials come from
  - Energy involved in production
  - Intended and unintended consequences of the use of the product
  - What happens to the product when it is no longer used



Systems-oriented Concept Mapping Extension (SOCME)

Sub-systems connections

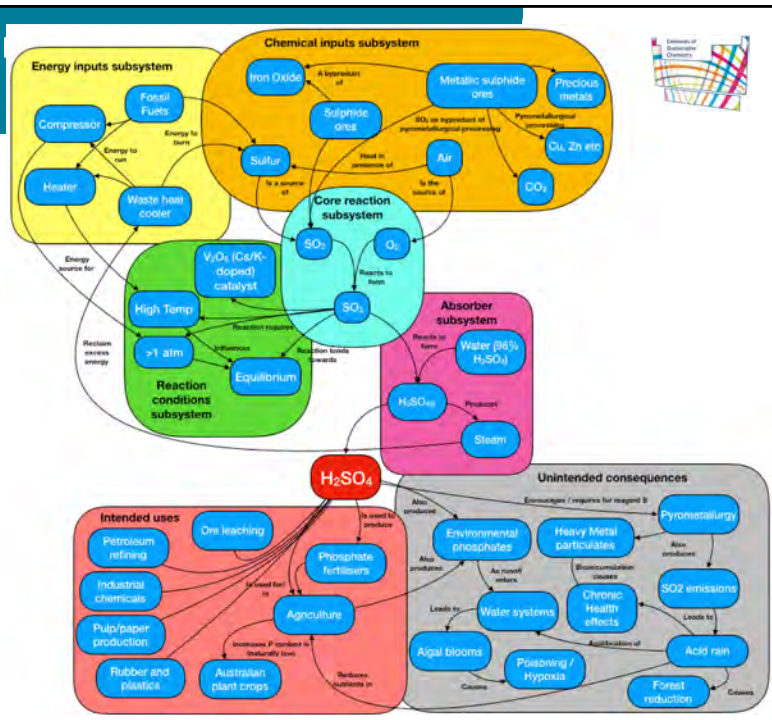
- Considering complexity with respect to subsystem connections



Systems-oriented Concept

Sub-systems connections

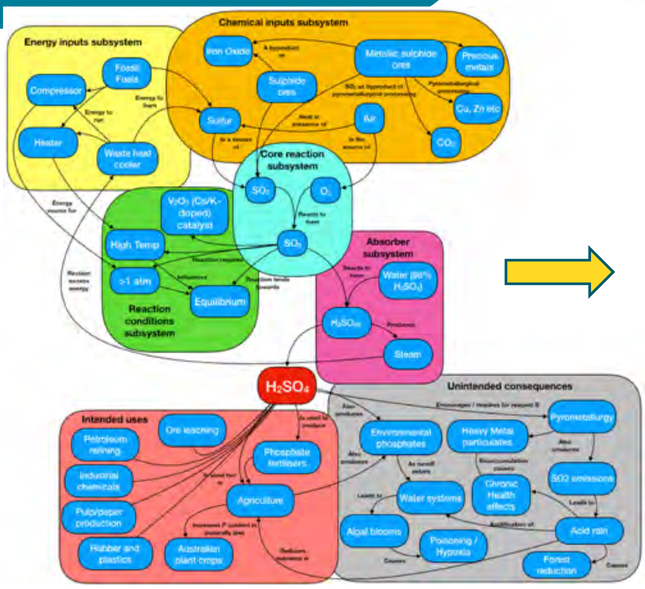
- Considering complexity with respect to subsystem connections

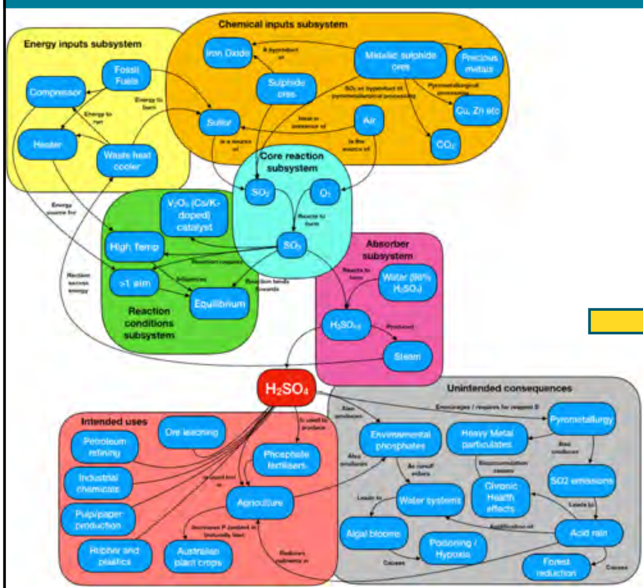


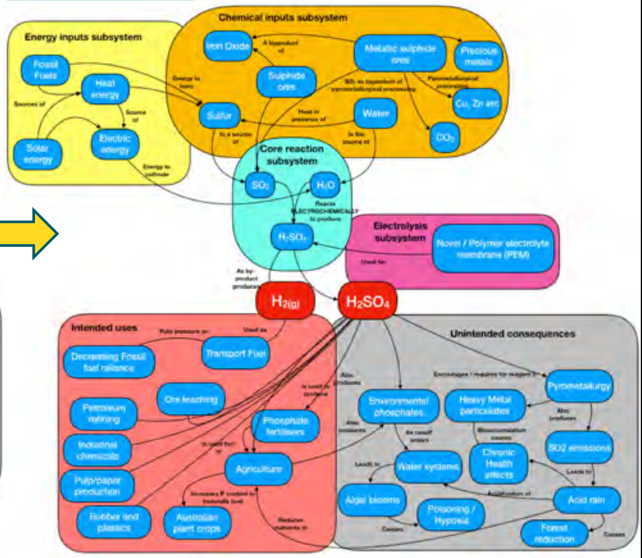
SOCME - Emergent concepts

And then….

…by looking at individual sub-systems, and connections between, can start to see how emergent concepts can change a system



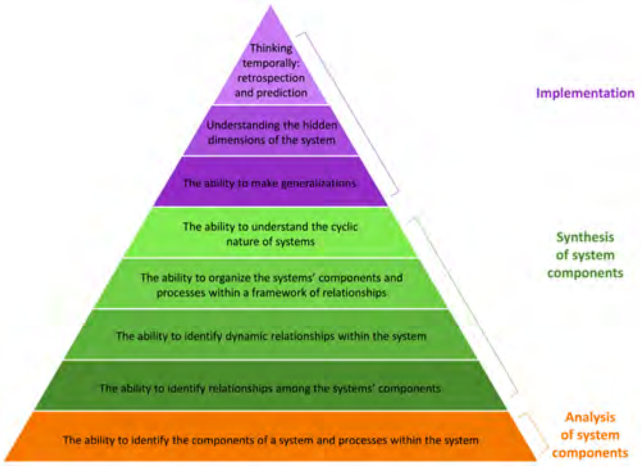




Systems thinking Hierarchy (STH) model

Orgill (2019) - A systems thinker can…

I. Identify the parts of a system
II. Visualise the interconnections and relationships between the parts in the system
III. Examine behaviours that change over time (dynamic or cyclic)
IV. Examine how systems-level phenomena emerge from interactions between the system's parts
V. Make generalisations, predictions on comparable systems



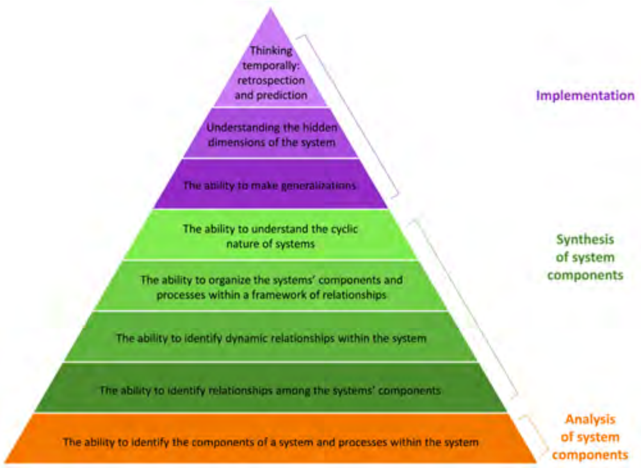
Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

Systems thinking Hierarchy (STH) model

Situate chemistry content in the real world context

Reductionist: $2NO_2 \rightleftharpoons N_2O_4$ to learn Le Chatelier's principle

Holistic: Dynamic and cyclic nature of photochemical smog in large cities (*increases* due to burning of fuels, *decreases* due to decomposition by sunlight)



Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

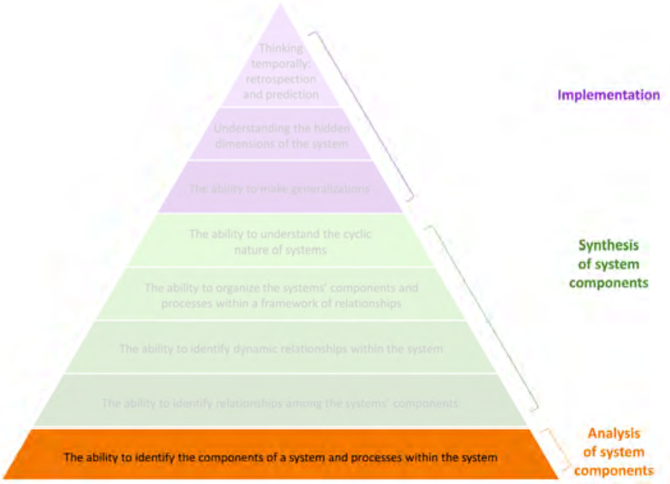
Systems thinking Hierarchy (STH) model

$2NO_2 \rightleftharpoons N_2O_4$ equilibria

Identify, quantify components -

Amount of NO_2 due to

- Combustion of fossil fuels
- Amount of sunlight
- Human actions



Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

31

Deakin University CRICOS Provider Code: 00113B

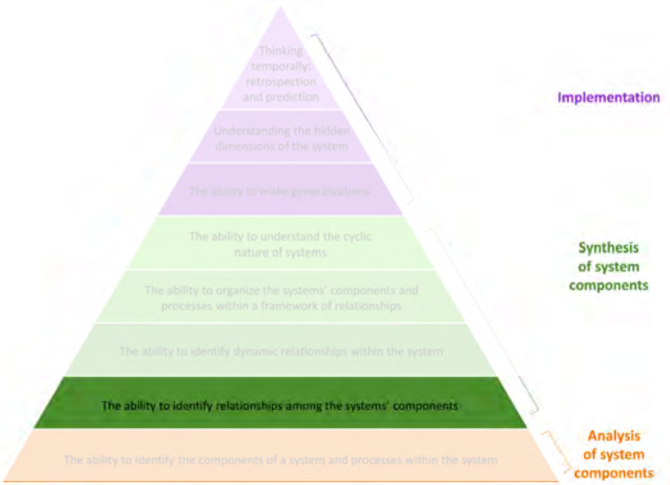
Systems thinking Hierarchy (STH) model

$2NO_2 \rightleftharpoons N_2O_4$ equilibria

Causation, identify relationships (chemical reactions) -

Amount of NO_2 related to

- Conversion of NO to NO_2
- Photochemical decomposition of NO_2



Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

32

Deakin University CRICOS Provider Code: 00113B

Systems thinking Hierarchy (STH) model

$2NO_2 \rightleftharpoons N_2O_4$ equilibria

Dynamism –

Students consider that NO_2 levels in a city change during the day

Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

Systems thinking Hierarchy (STH) model

$2NO_2 \rightleftharpoons N_2O_4$ equilibria

Organise/Quantify relationships, measure of interconnectedness -

Consider the *relative* rates of these two reactions (NO to NO_2, photochemical decomposition of NO_2), and their effect on concentration of NO_2

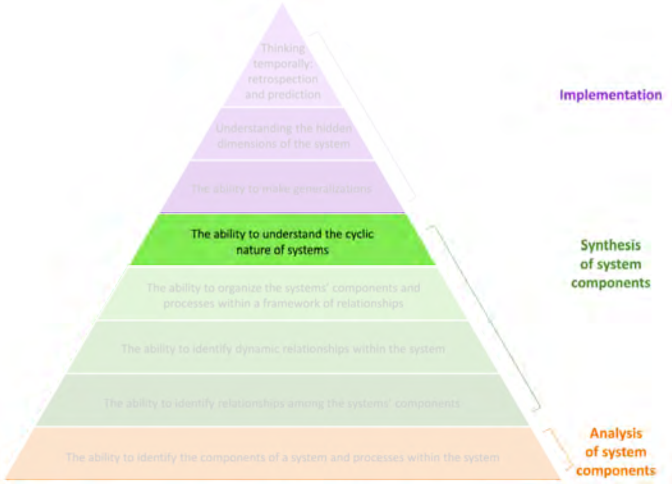
Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

Systems thinking Hierarchy (STH) model

$2NO_2 \rightleftharpoons N_2O_4$ equilibria

Cyclic nature –

Students discover that NO_2 concentration increases in the first part of the day and then decreases in the last part of each day



Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

35

Deakin University CRICOS Provider Code: 00113B

Systems thinking Hierarchy (STH) model

$2NO_2 \rightleftharpoons N_2O_4$ equilibria

Interconnectedness to other systems -

Students consider what parts of the system increase/decrease NO2

Make generalisations – which of these impact other systems? Other atmospheric gases?

Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

36

Deakin University CRICOS Provider Code: 00113B

Systems thinking Hierarchy (STH) model

$2NO_2 \rightleftharpoons N_2O_4$ equilibria

Recognising impact of "hidden", "invisible" –

Microscopic – water molecules, gases, solvents

Large-scale – population factors, ethical factors

Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

37

Deakin University CRICOS Provider Code: 00113B

Systems thinking Hierarchy (STH) model

$2NO_2 \rightleftharpoons N_2O_4$ equilibria

Feedback, interaction with its environment –

- The more photochemical smog, the less people go outside.
- Fewer people walking to work, more people driving
- Greater the future build-up of NO_2

Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

38

Deakin University CRICOS Provider Code: 00113B

Systems thinking Hierarchy (STH) model

$2NO_2 \rightleftharpoons N_2O_4$ equilibria

Make predictions based on current factors -

- NO_2 levels have varied, but increased over time
- Rationalise influence of *factors* on predicting future behaviour

Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

39

Systems thinking Hierarchy (STH) model

$2NO_2 \rightleftharpoons N_2O_4$ equilibria

Extend to consider health, economic, ethical factors -

- Health impact of those living in big cities
- Economic impact of these health complications
- Social justice issue for those unable to afford to live outside of city
- Ethical issues and democratic participation in taking actions

Orgill, M., York, S., & MacKellar, J. (2019). Introduction to Systems Thinking for the Chemistry Education Community. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00169

40

Deakin University CRICOS Provider Code: 00113B