Situating sustainable chemistry in teaching and learning with systems thinking

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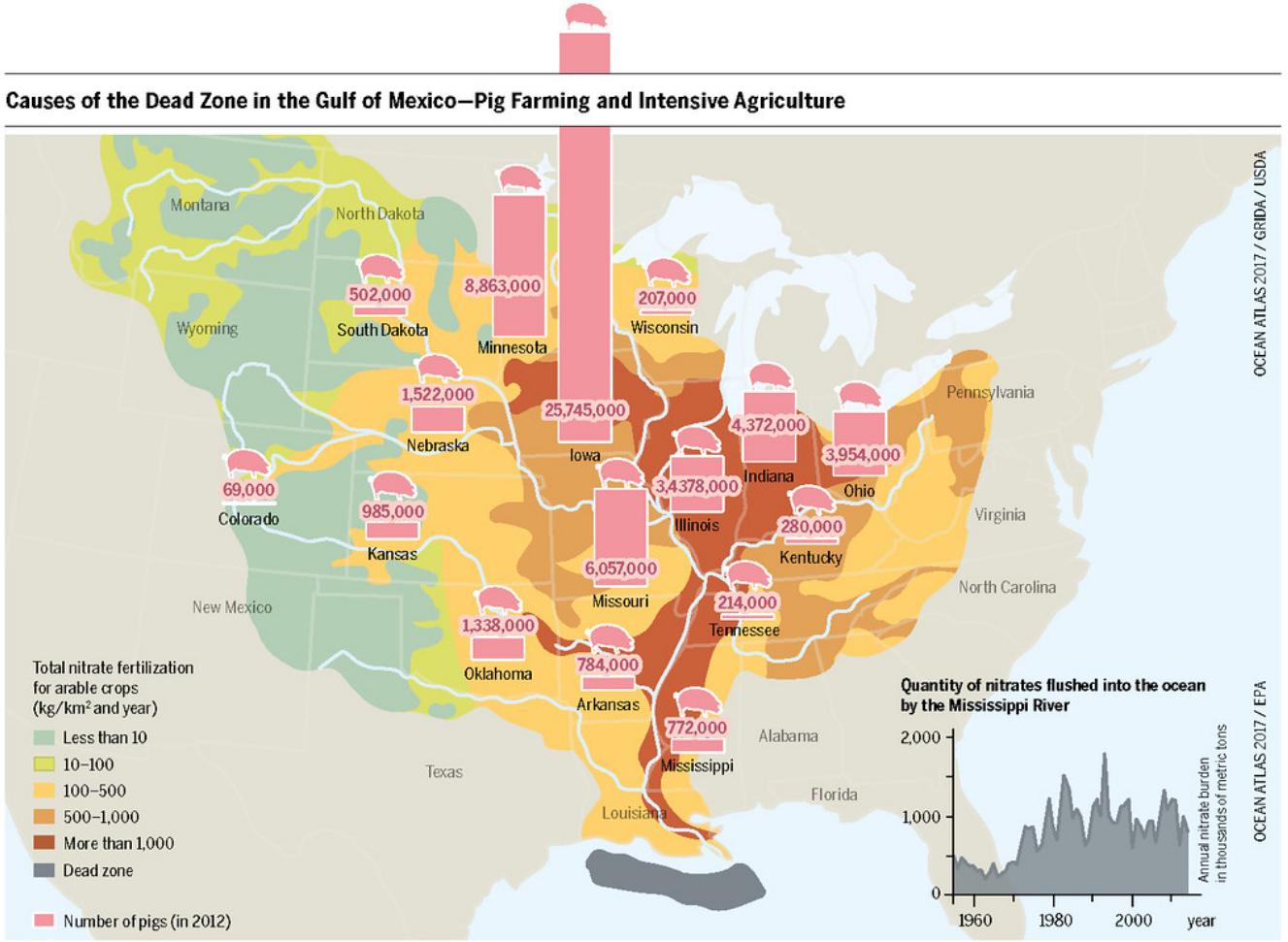
Chemistry and sustainable development

‘Peak phosphorus’



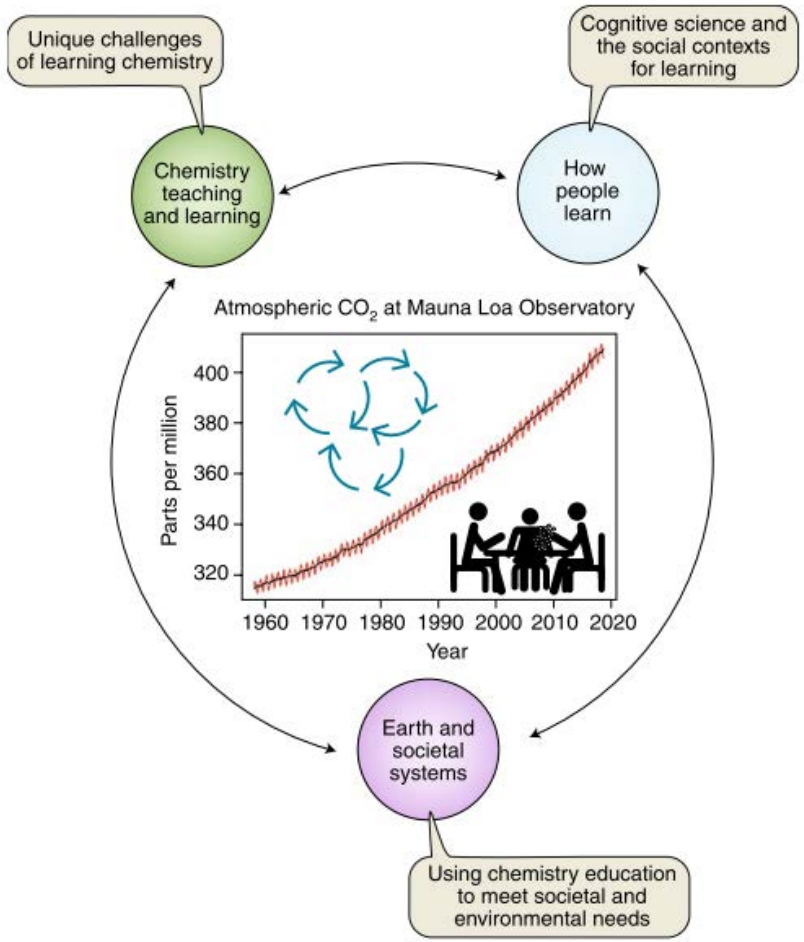
Chemistry and sustainable development

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?

Systems Thinking in Chemistry Education (STICE)



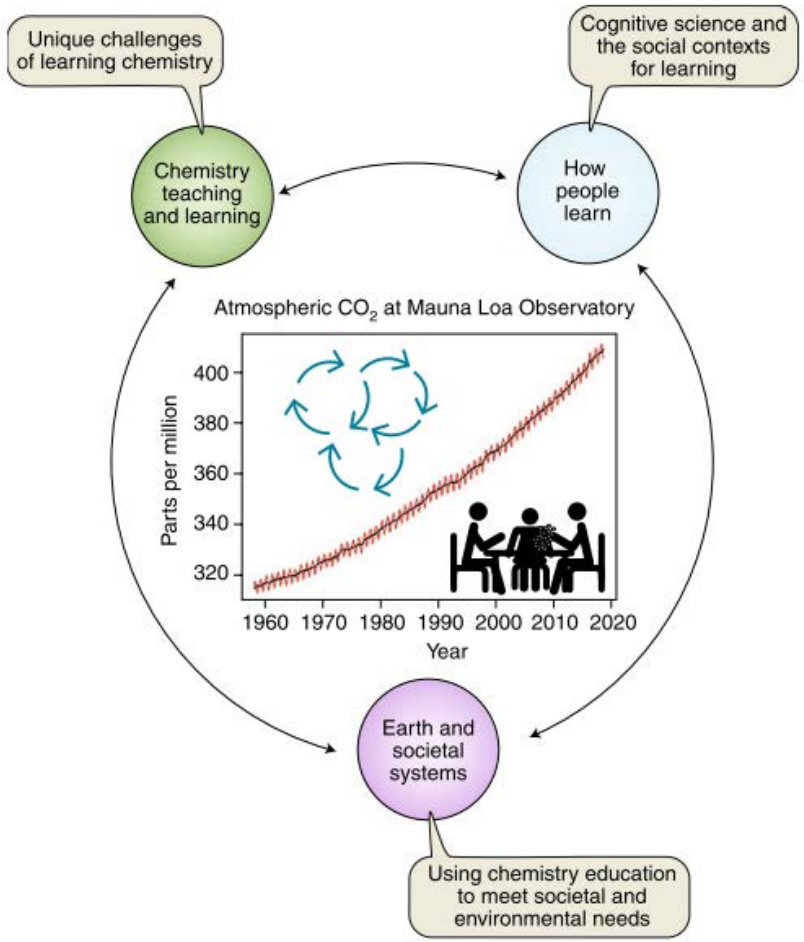
IUPAC Task Group (2017 – Present)

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

- Incorporates critical thinking and problem solving
- Incorporates scientific investigation and design thinking by emphasising innovation
- Reduce reductionist teaching in chemistry
- Place learner (and chemistry) in real world context

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"

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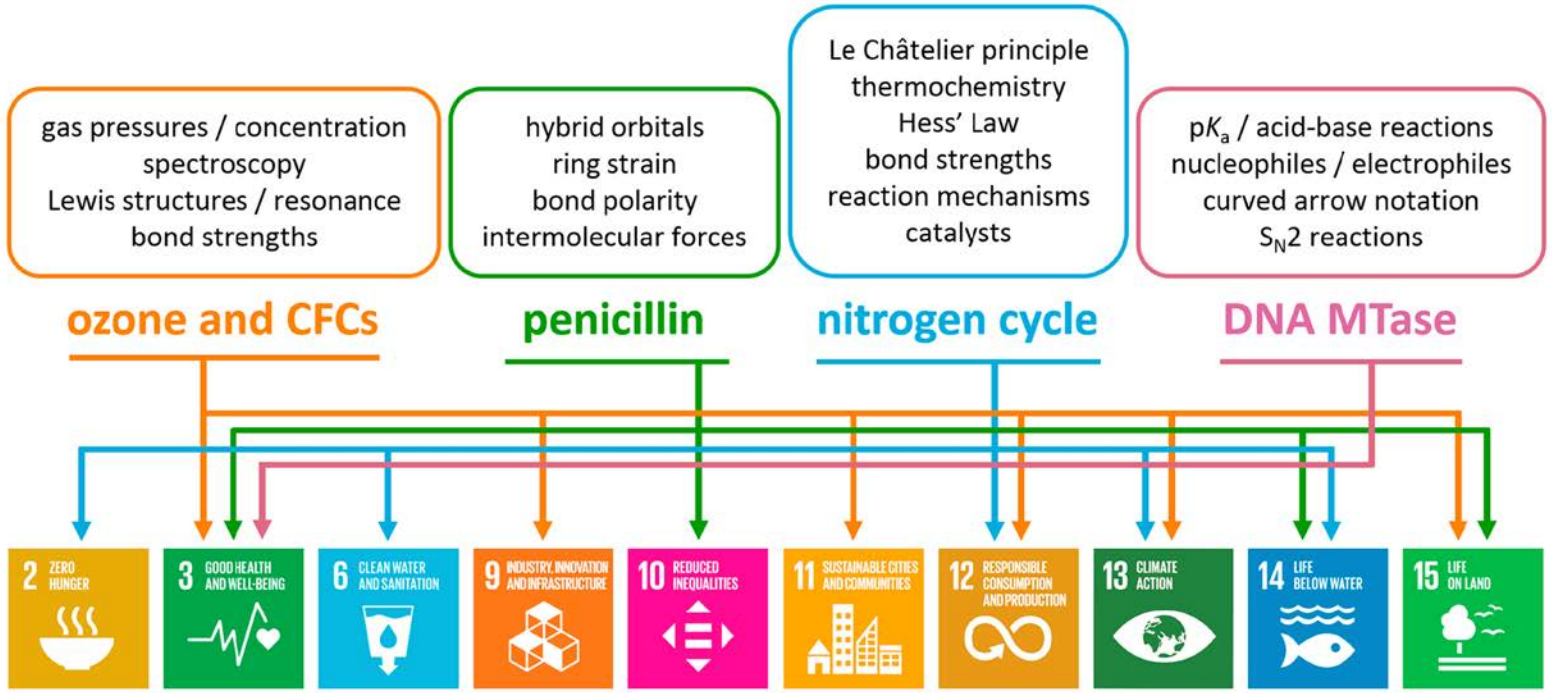
Chemistry and sustainable development

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

Future directions for STICE – What's next…

1. Developing Systems Thinking Resources for Chemistry Educators and Students
   - Priority: Develop and Explore Systems-Thinking- Related Learning Outcomes (LOs), Resources, Activities, and Assessments
   - Priority: Connect Systems Thinking Approaches to Curriculum and Program Standards
   - Priority: Design and Implement Chemistry Educator Training in Systems Thinking Approaches

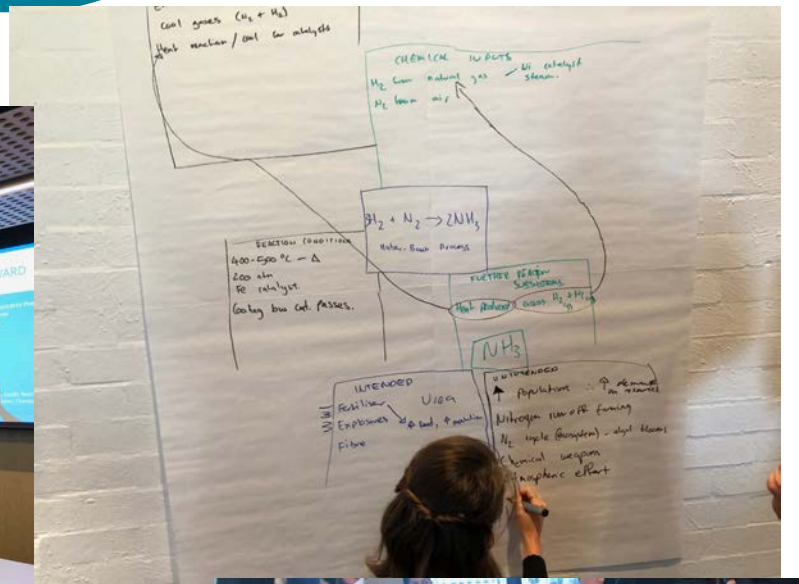
2. Identifying Chemistry Education Research Needed To Investigate and Improve Systems Thinking Approaches

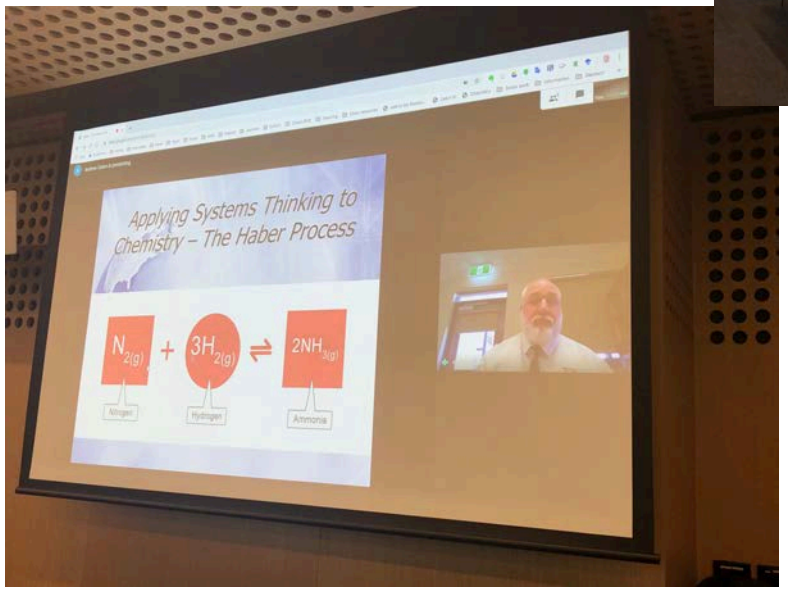
3. Investigating Opportunities To Apply Chemistry-Related Systems Thinking Approaches to Broader Educational Contexts

Flynn, A. B., Orgill, M., Ho, F. M., York, S., Matlin, S. A., Constable, D. J. C. & Mahaffy, P. G. (2019) Future Directions for Systems Thinking in Chemistry Education: Putting the Pieces Together. *Journal of Chemical Education*. doi: 10.1021/acs.jchemed.9b00637

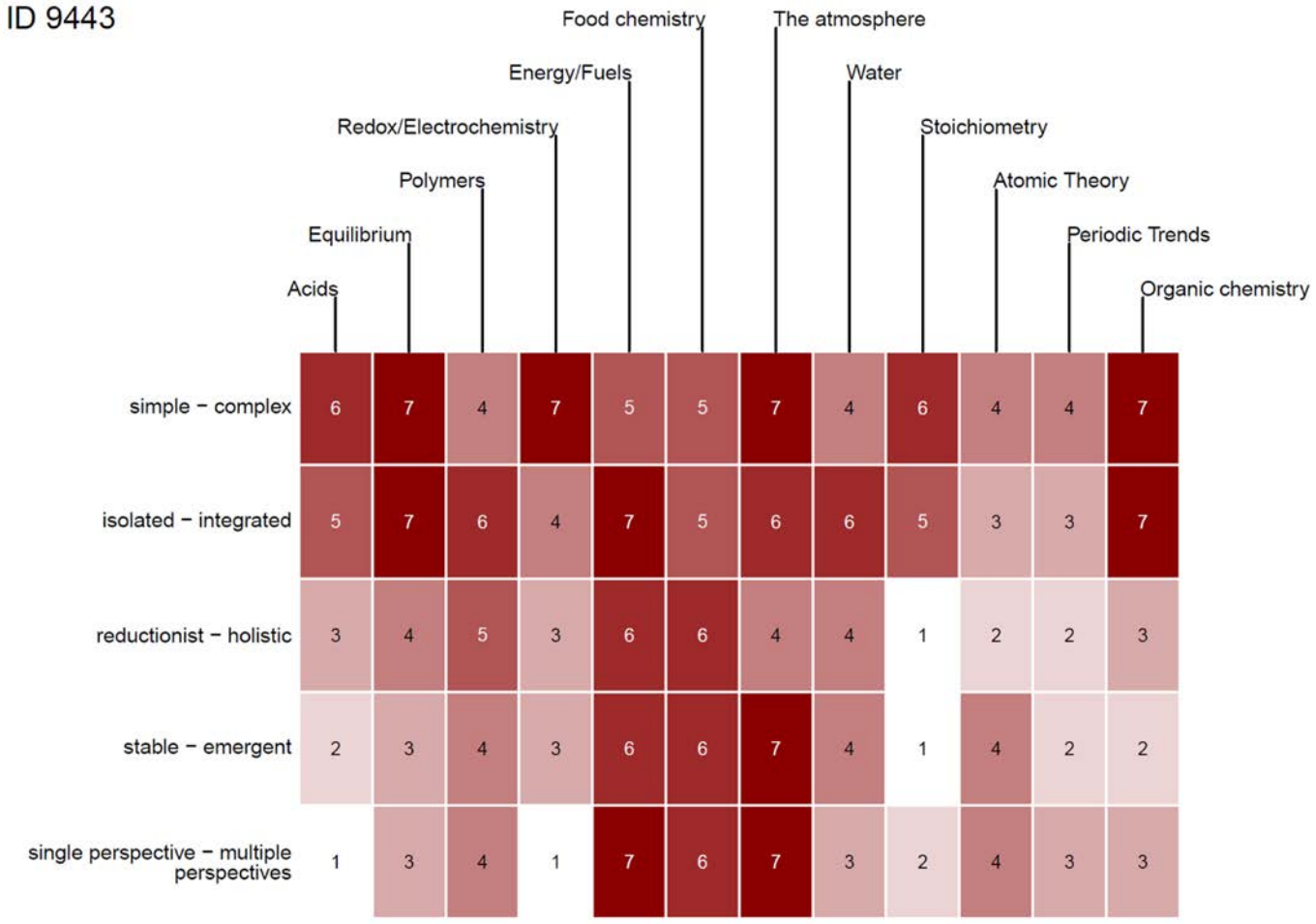
STICE workshops at Deakin - 2019

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





Connecting approaches to curriculum content

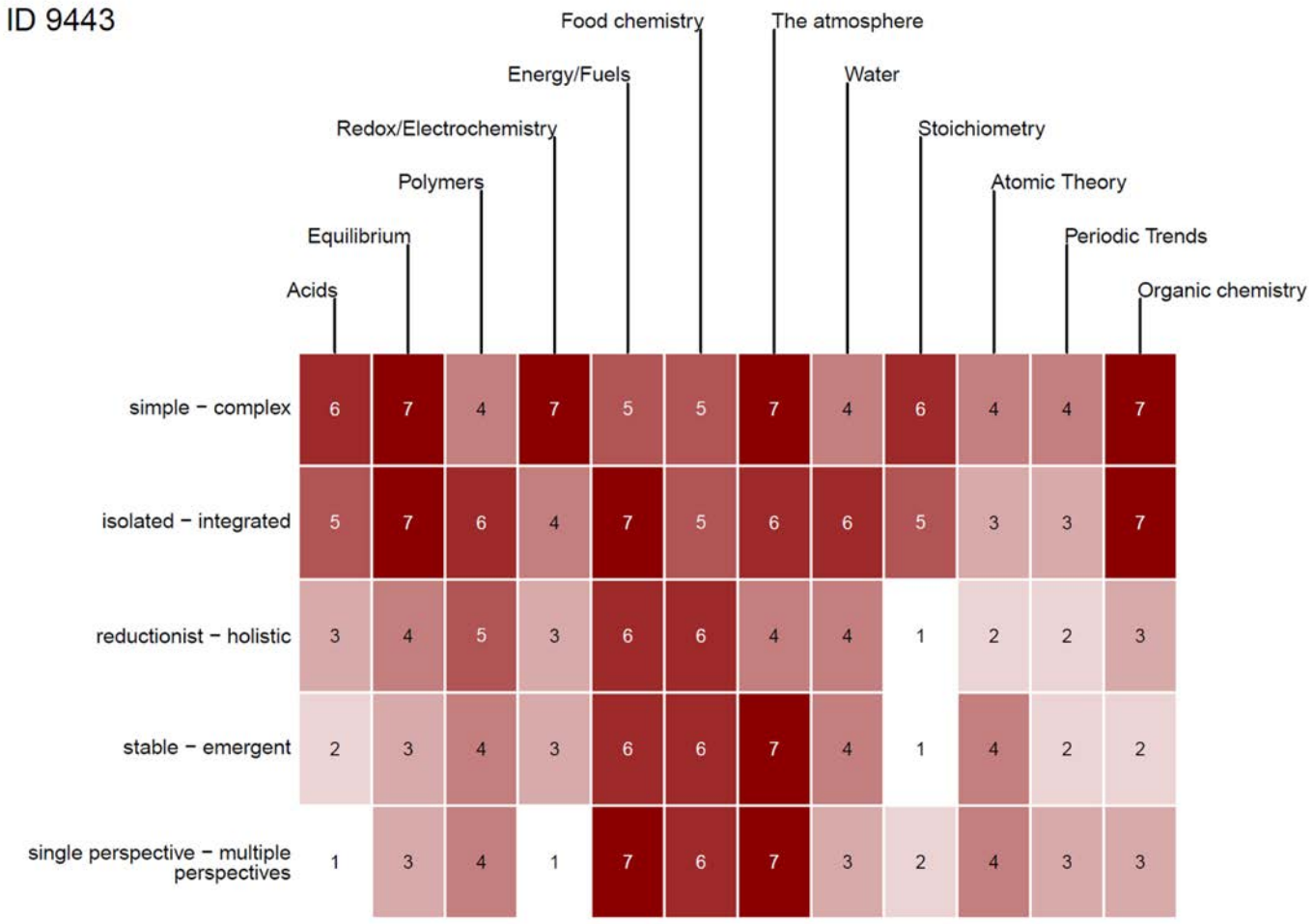


Schultz. et al (unpublished)

Teacher and researcher workshops

- **Repertory grid** to interrogate applicability of chemistry topics to systems thinking
- list of topics in the secondary curriculum
- **Separately** to secondary and tertiary workshop participants

Connecting approaches to curriculum content



Schultz. et al (unpublished)

Simple
Few components, easy to understand, no uncertainty

Complex
Many components, difficult to understand, multidimensional

Isolated
Unrelated to other topics, can be interpreted or understood in isolation

Integrated
Interdependent; cannot be interpreted or understood without reference to other topics

Reductionist
Scientific concepts described in terms of simple or fundamental components

Holistic
Scientific concepts able to be described only in respect to the bigger picture or system, 'part of the whole'

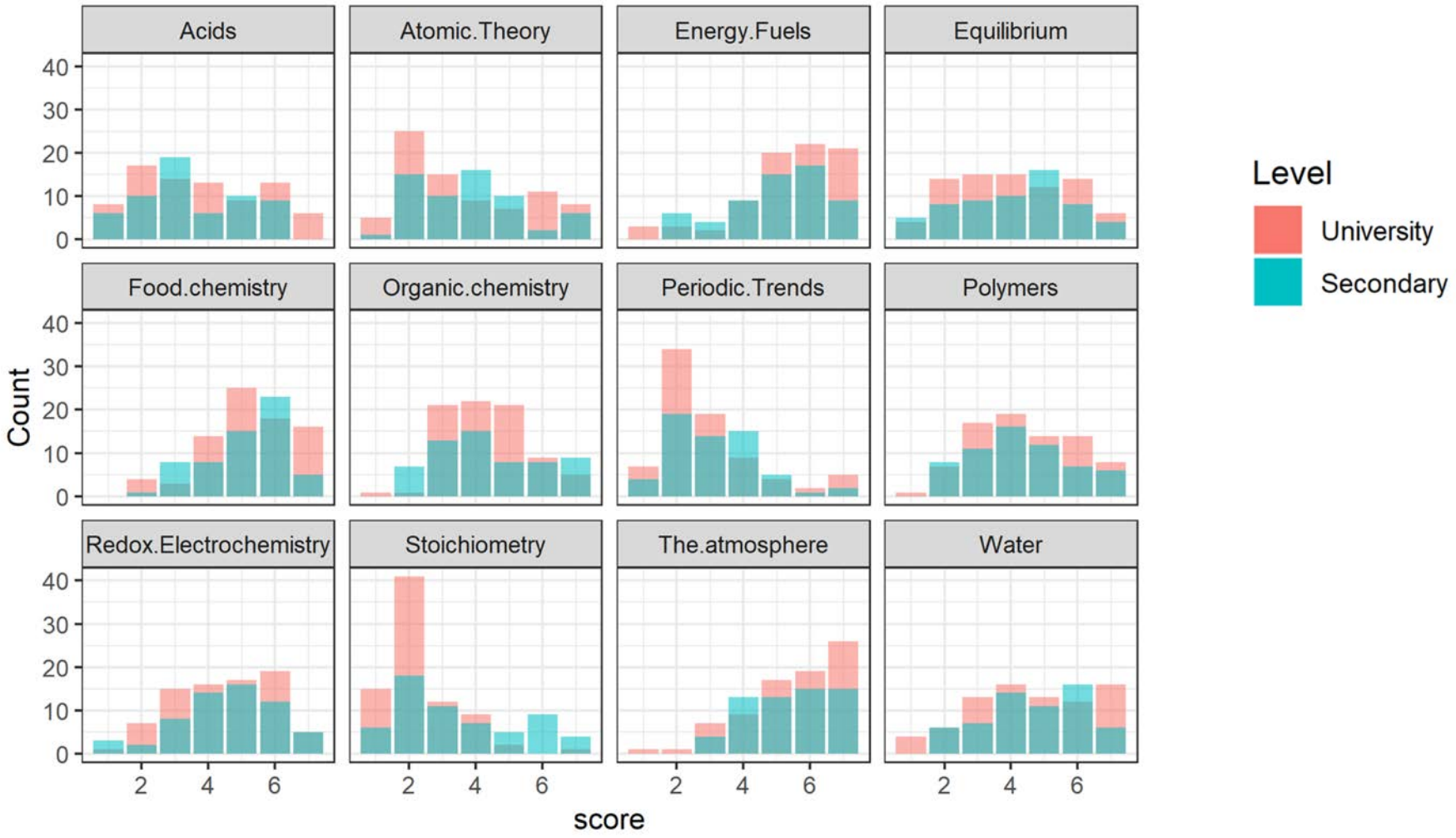
Stable
Interpretation or understanding of topic has not changed much over (recent) time

Emergent
Interpretation or understanding of topic has rapidly changed over (recent) time

Single Perspective
Only one way of looking at it or understanding it

Multiple Perspectives
More than one way of looking at it or understanding it

Connecting approaches to curriculum content



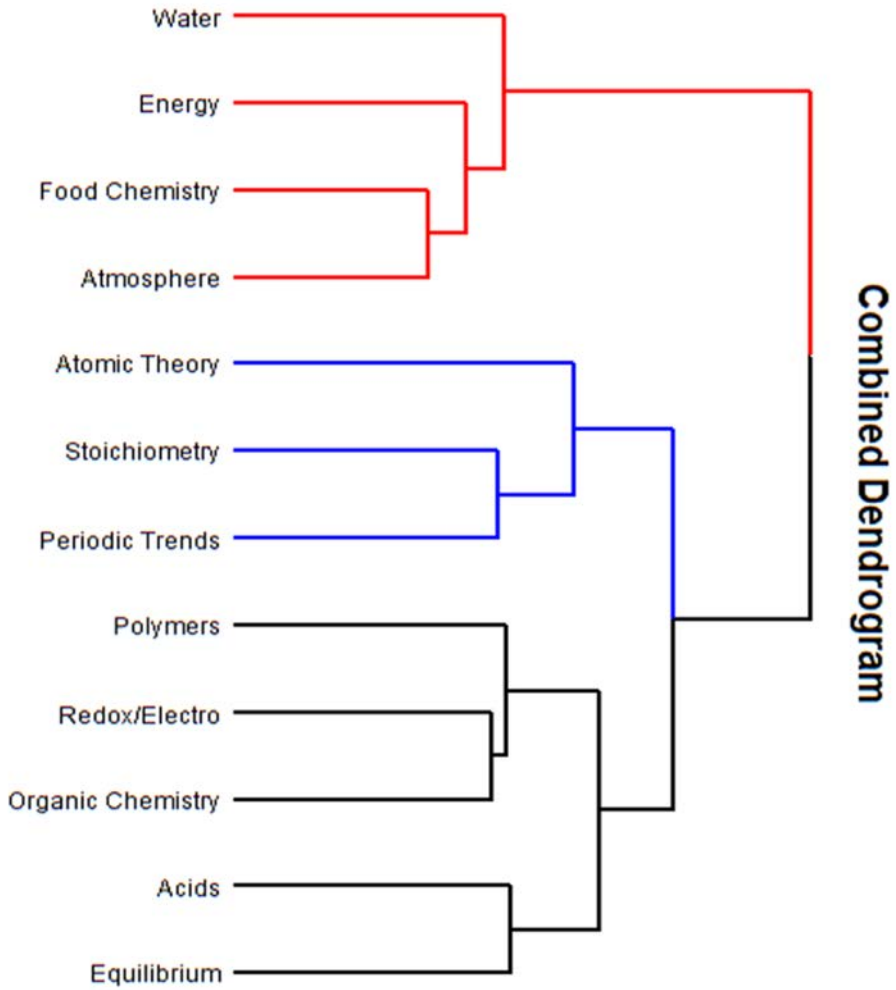
Schultz. et al (unpublished)

Connecting approaches to curriculum content

Perceived as aligned with systems thinking

Perceived as not aligned with systems thinking

Perceived as **modifiable** to systems thinking

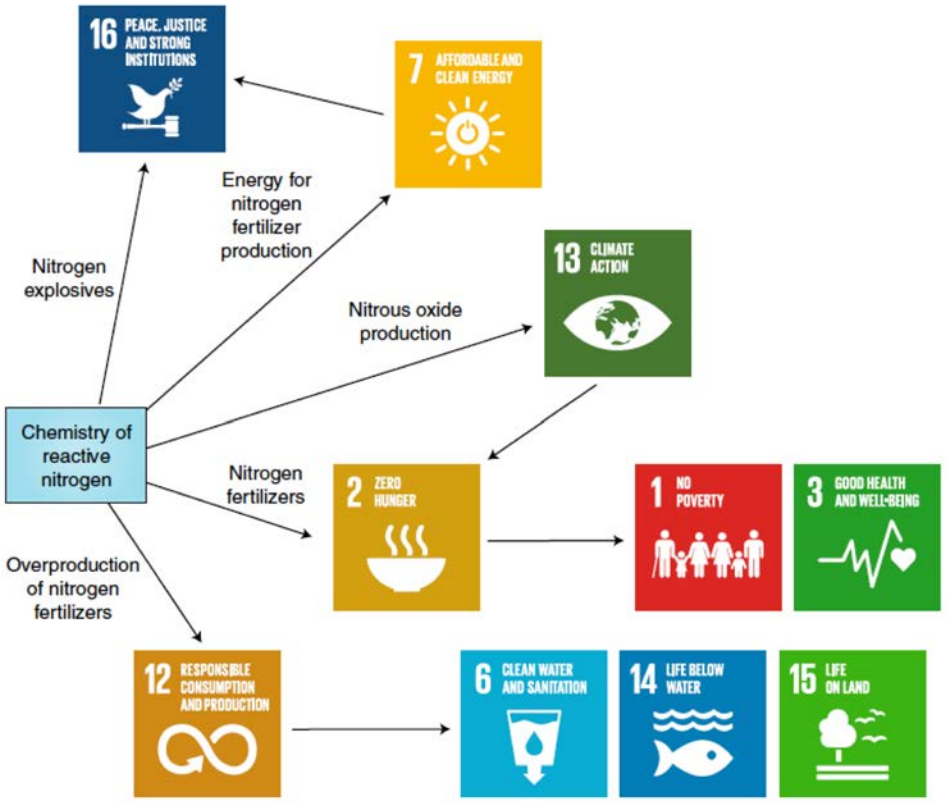


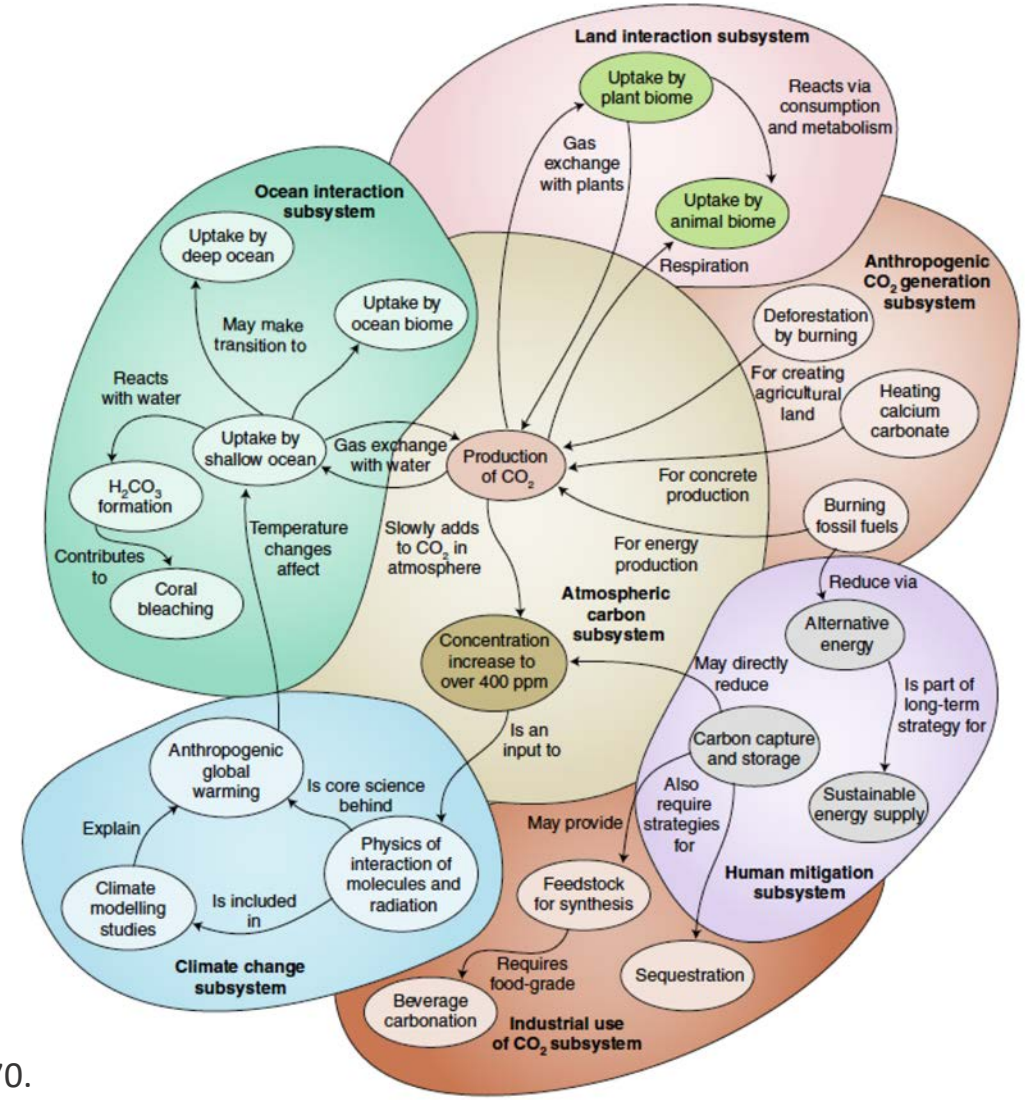
Teacher and researcher workshops

- Identifying topics as ‘low hanging fruit’ for Systems Thinking implementation

Schultz. et al (unpublished)

Evaluating systems thinking - Systems Maps





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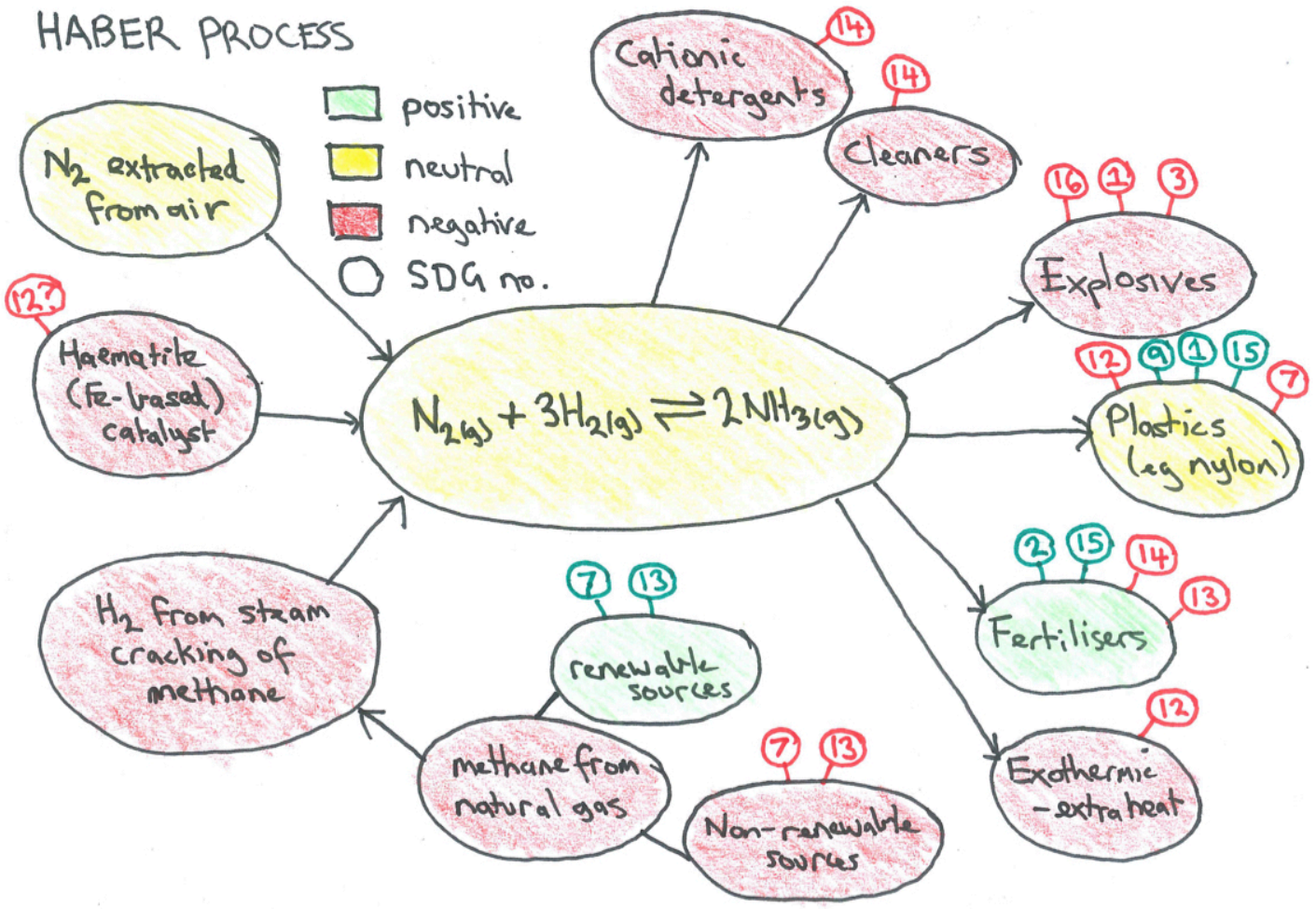
Evaluating systems thinking - Systems Maps

Teacher action research and student impact evaluation

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

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
- 2019-2020 cohort study underway (*pre/post surveys, mapping analysis, interview*)

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

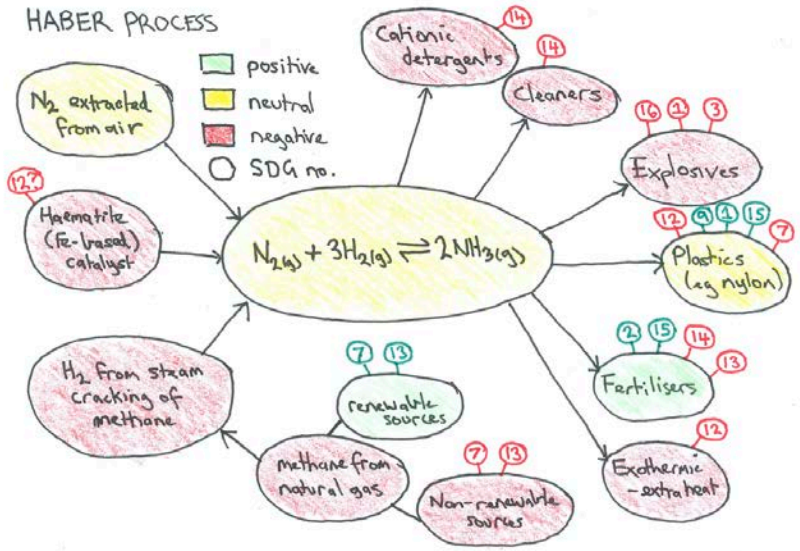
How many components in their map?

- RELEVANT components (stated SDG relevant to context)?

How many connections (linking arrows) in the map?

- how many positively labelled linking arrows?
- how many negatively labelled linking arrows?

Did they consider ENERGY inputs and outputs?



Evidence chemical process considered as a DYNAMIC process?

How many RELEVANT INTENDED uses of chemical process (beyond production of fertiliser)?

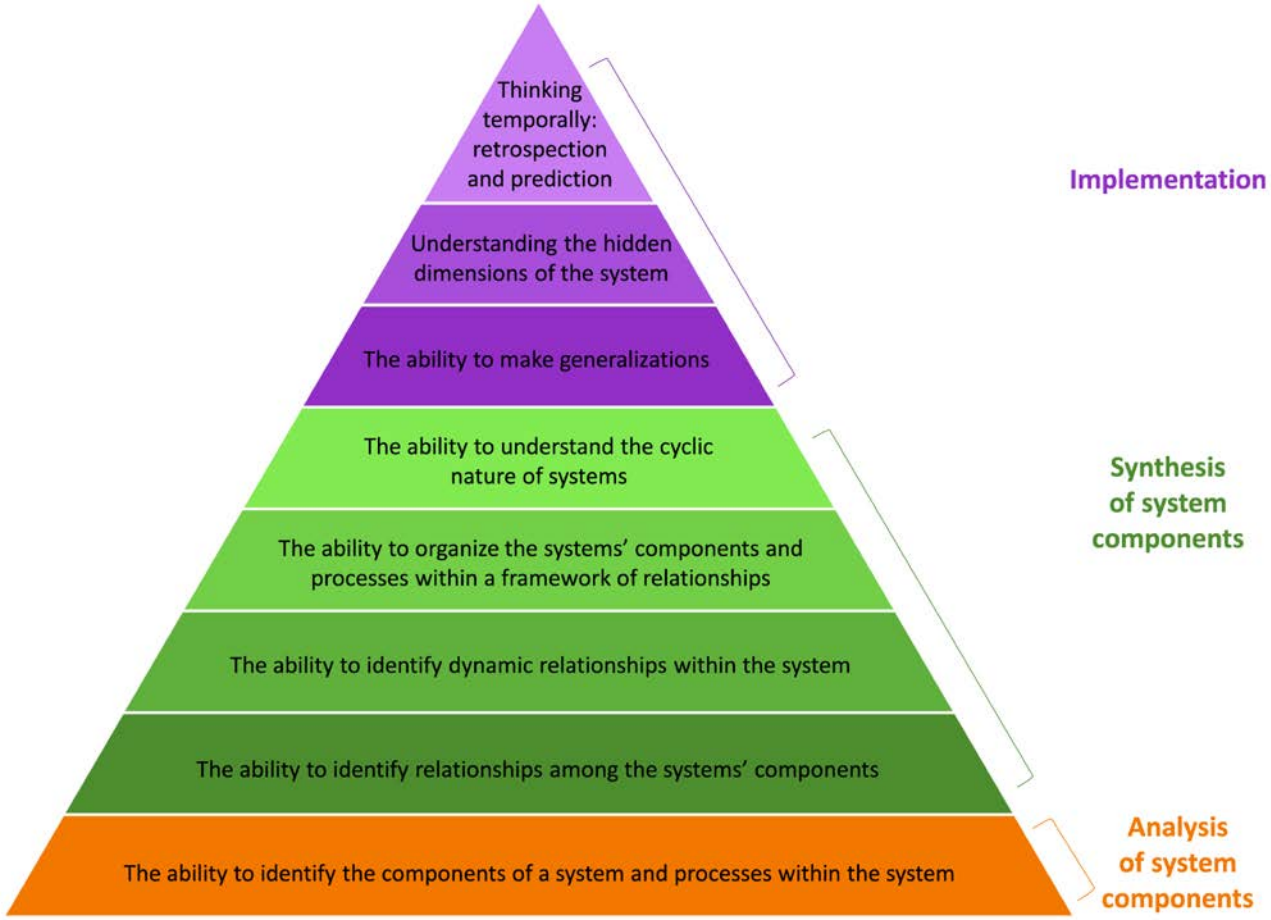
How many UNINTENDED consequences?

- Also, how many are relevant to waste products from human activities

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

Evaluating systems thinking –students pre/post

Possible measurement of change in systems thinking?

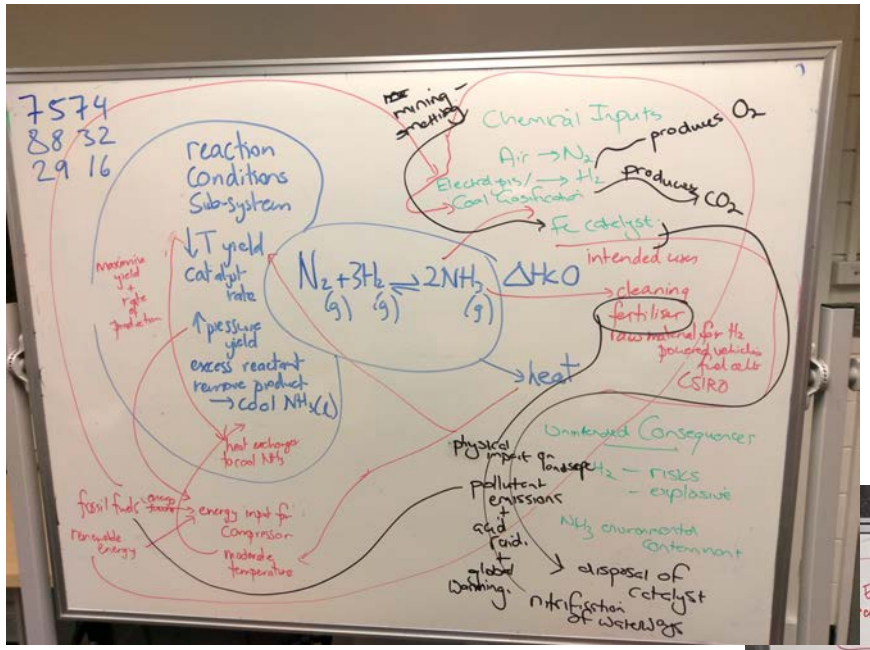
I am confident in… (5 point Likert scale)

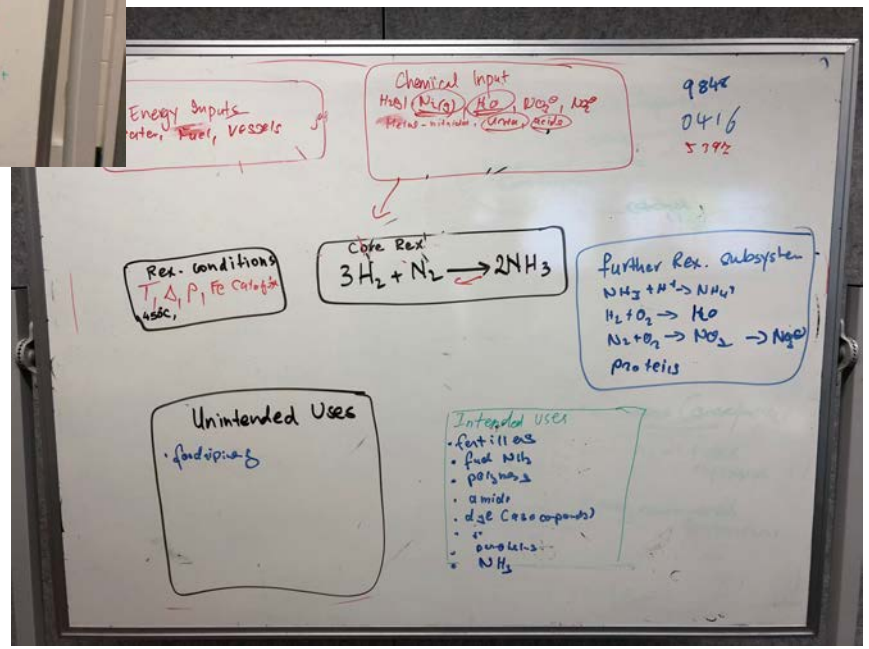
- *Realising that problems have multiple parts*
- *Analysing multiple aspects of a problem*
- *Seeing links between parts of a problem*
- *Describing how the links between parts of a problem change over time*
- *Solving a problem by looking at how the parts work together*

Current pre and post-survey question in

- Yr12 Depth Study 2019/2020 students, correlated with mapping exercise
- Example question for Chem-focussed professional learning community (2020)

Evaluating systems thinking - Systems Maps

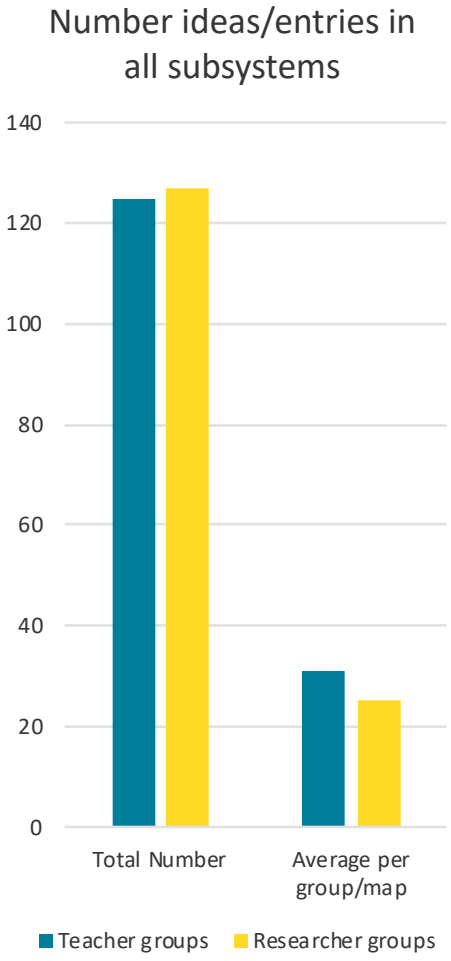


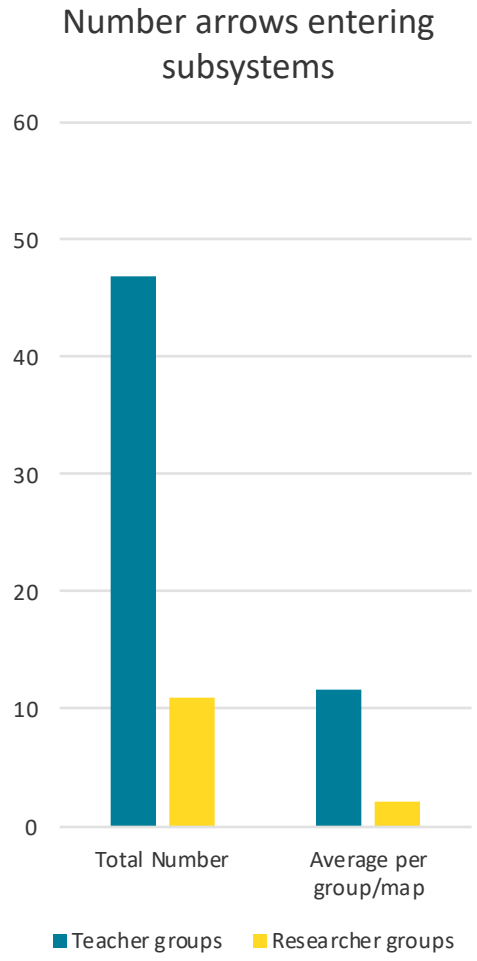


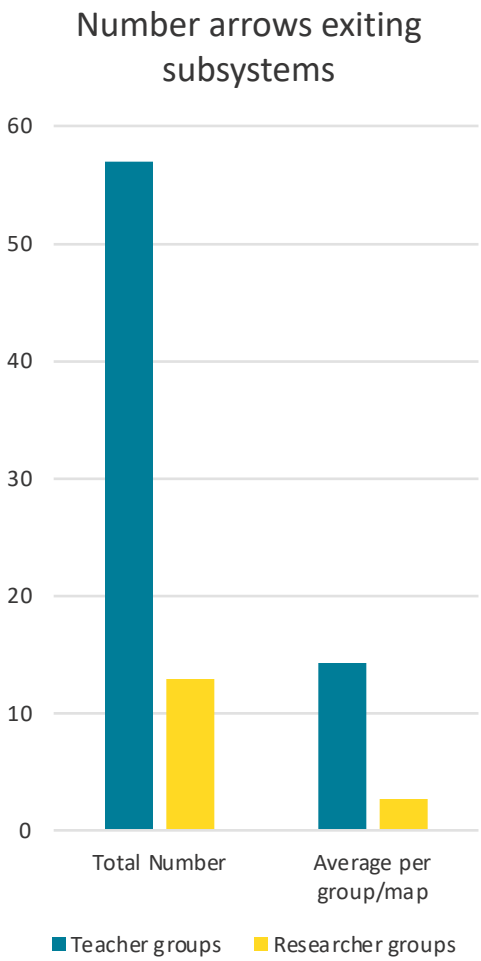
Modeling complexity

- Systems-oriented concept map extension (SOCME)
- Visualise the interconnectedness of sub-systems (mass, energy, reaction conditions, consequences)
- **Separately** with secondary and tertiary workshop participants

Evaluating systems thinking - Systems Maps







Modeling complexity

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Evaluating STICE – Workshop participants

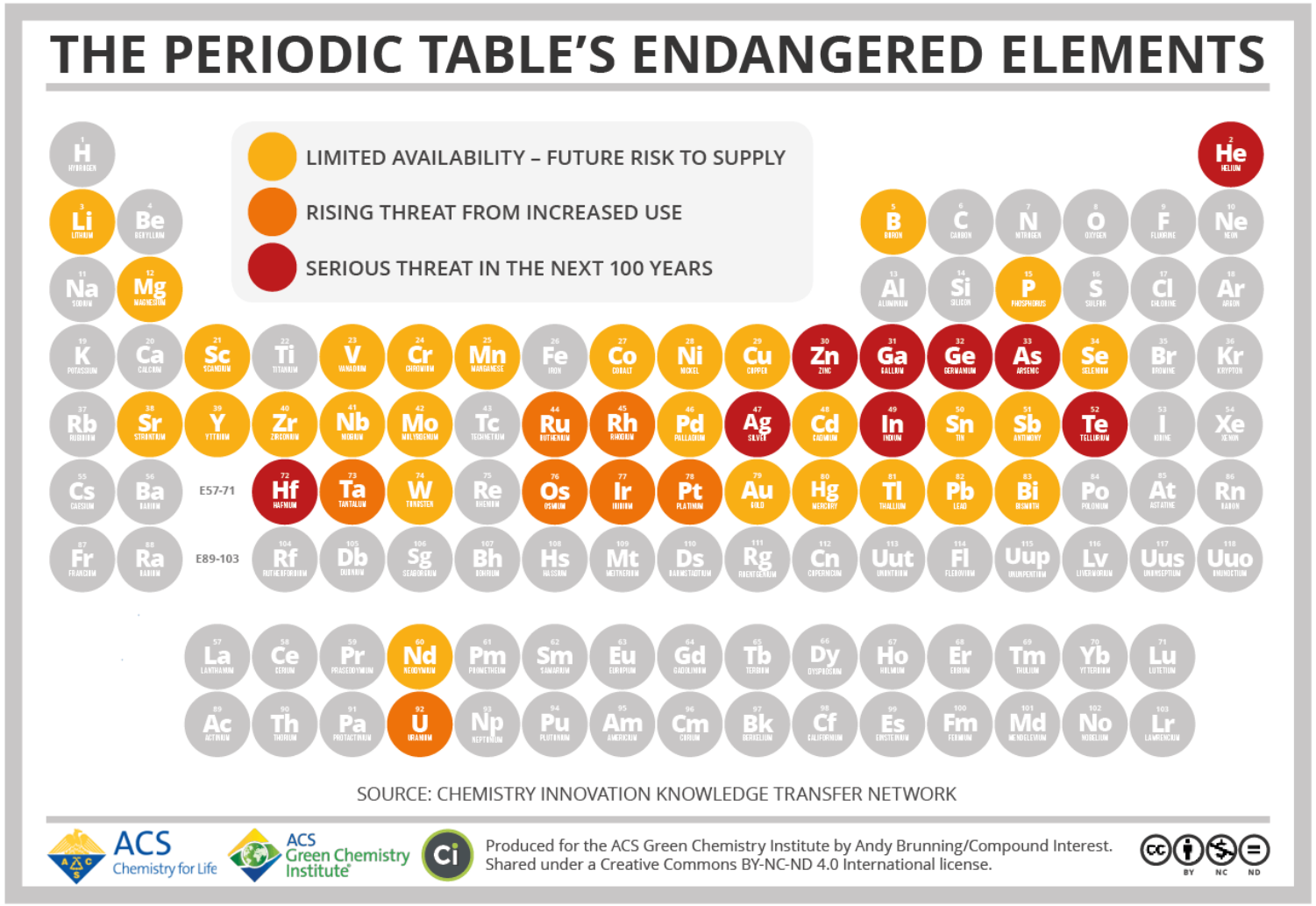
27 workshop participants (12 secondary teachers, 15 tertiary lecturers/researchers)

- 9 Focus groups interviews (4 secondary, 5 tertiary)
- Inductive thematic analysis (underway, 2 coders)

Some initial themes (preliminary coding)

- Identity. Teachers and academics identify as chemists, but they see it as harder to do as students who seem to have fewer real-life connections to chemistry these days.
- Prior conceptual understanding required to realise the value of STICE, to productively engage in this systems thinking (certain amount of front-loading).
- Students need to engage with STICE as part of their developing citizenship (interesting links to ethics).
- Current curriculum structures and assessment processes are a limiting factor. But also what students expect learning to be, which is conditioned again by the curriculum and testing regime

Endangered Elements

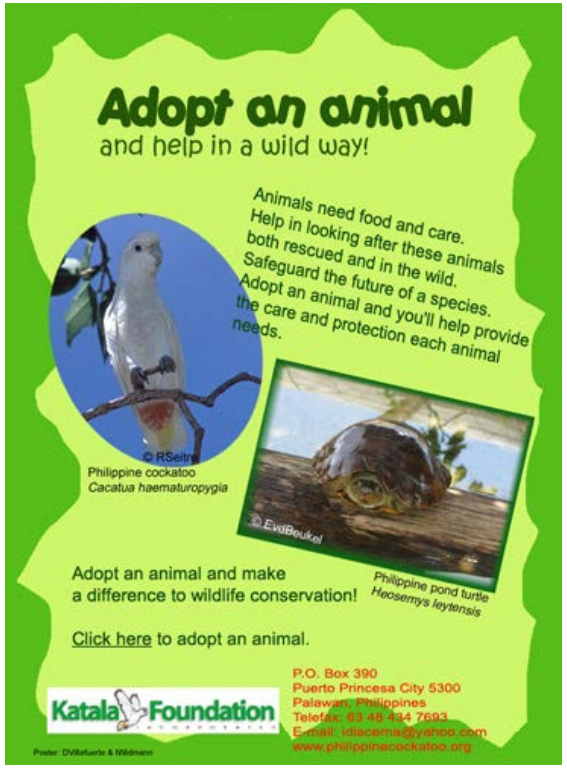


- How are they 'endangered'?
- Where and What are they sourced from?
- What are they used for?
- What happens when they become scarce?

https://www.compoundchem.com/2015/08/19/endangered-element

Endangered Animals… or Elements?

Quick suggestion: Adopt an Endangered ‘Element’ campaign?



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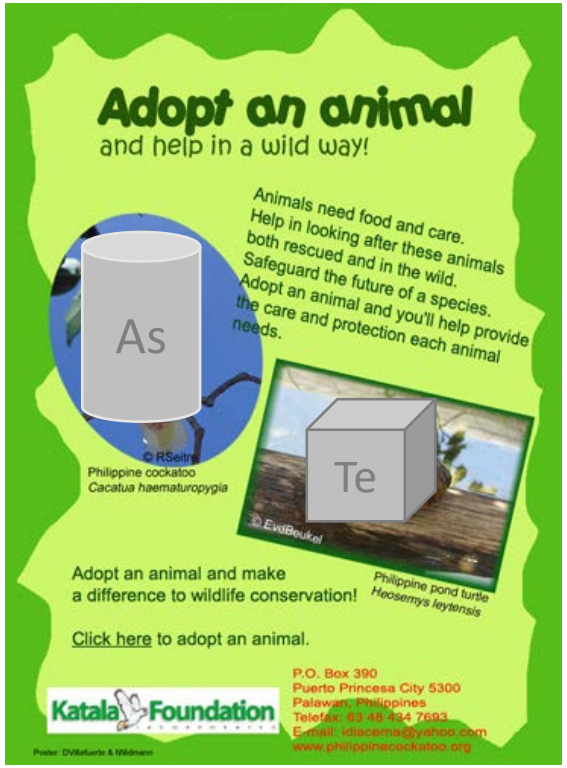


Periodic Table of Sustainable Elements

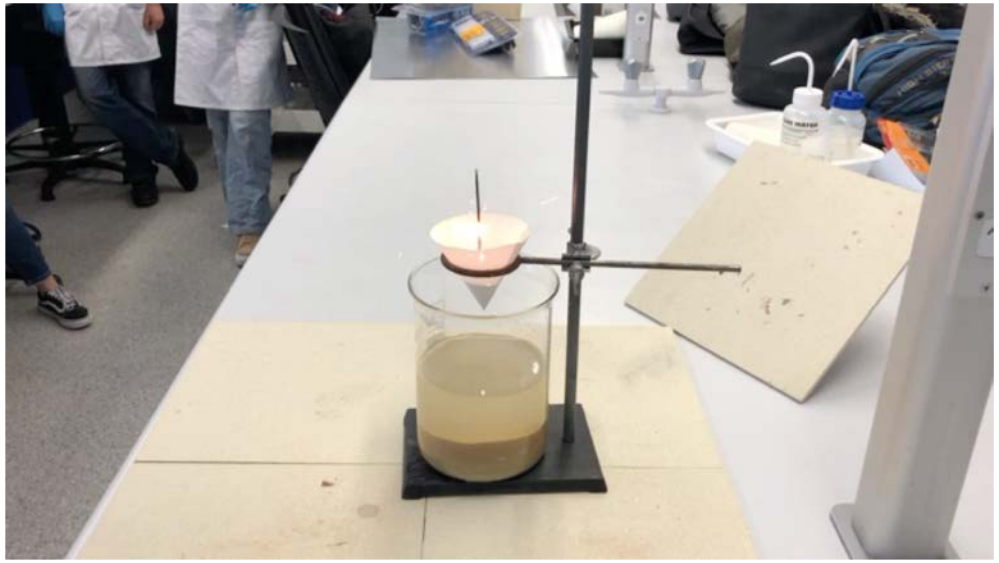
- Chemistry-based school outreach program
- Upper prim / Lower sec students (11-14 year-olds)
- Australian National Commission for UNESCO grant winner 2019
- Modelled on National Indigenous Science Education Program (NISEP)
- Using practical activities to demonstrate the **relevance** of chemistry to sustainability

The Periodic Table of Sustainable Elements:

An Outreach Program of school activities for learning and engagement

To celebrate the **International Year of the Periodic Table** in 2019

this project involves secondary students participating in hands-on, inquiry-focussed chemistry activities. Students will learn about the relevance of chemistry to sustainability.



Elements of Sustainable Chemistry

United Nations Educational, Scientific and Cultural Organization

Australian National Commission for UNESCO

The Periodic Table of Sustainable Elements has received grant funding from the Commonwealth Government through the Australian National Commission for UNESCO

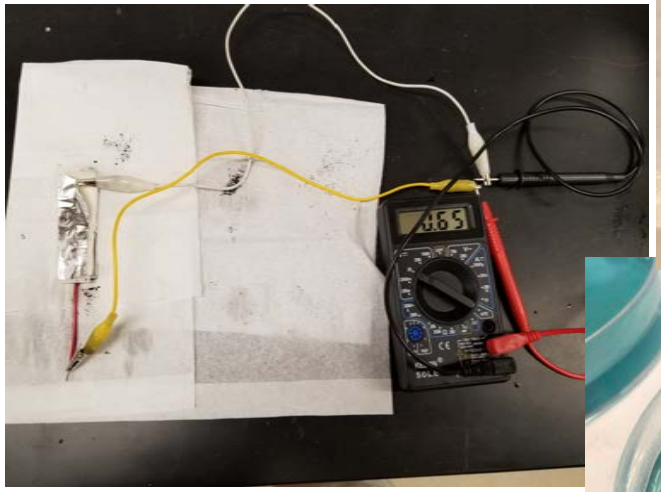
Periodic Table of Sustainable Elements

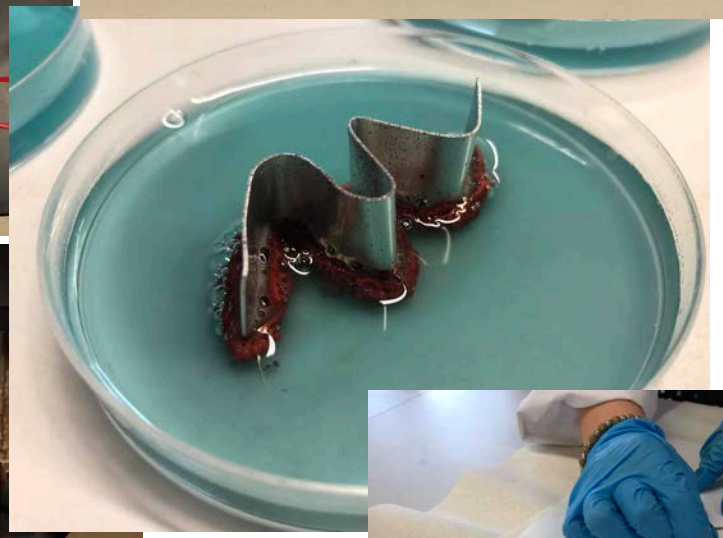
Practical activities highlighting elements

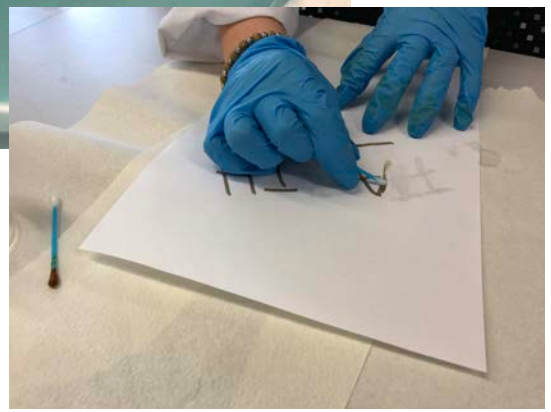
- Aluminium-Air battery
- Copper crystals growing on Al sheets in agar gel
- Zinc plating on copper coins

Energy in/out of Aluminium production

- 3% of global electrical supply used to extract Aluminium



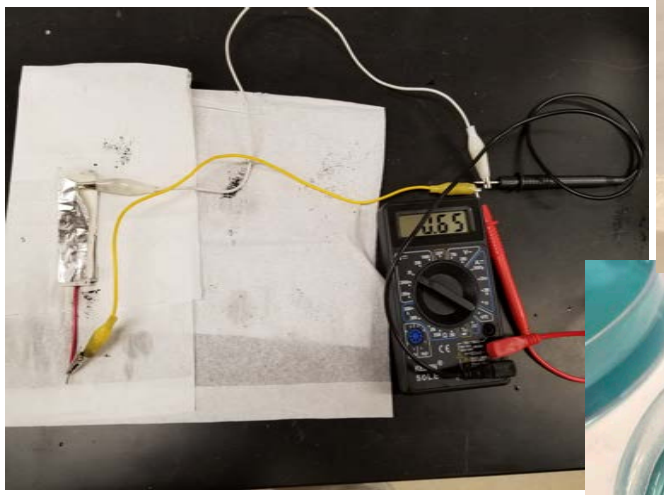


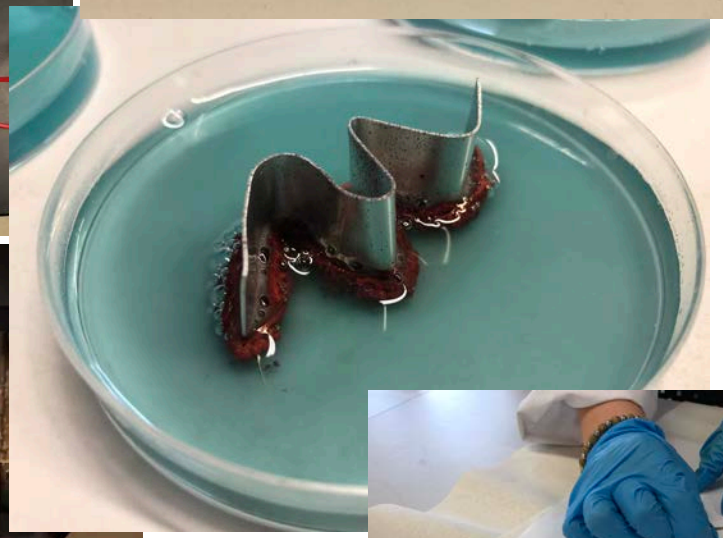


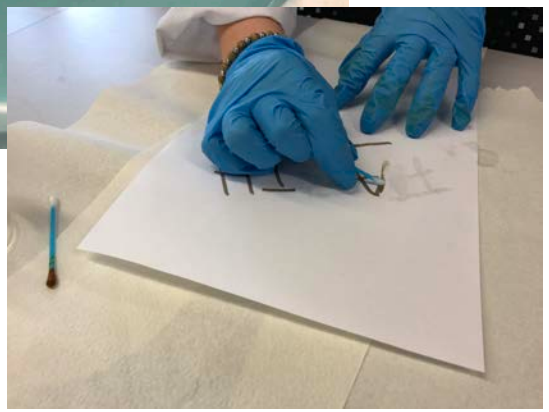
Periodic Table of Sustainable Elements

Research Evaluation

- 5 Schools, ~820 students
- Participants: 2 min, 4 Qs pre/post survey
- 'Student leaders' (10-12 per school): 7 min, 11Qs, pre/post survey
- Teachers: Post survey, follow-up interview
- Uni Student volunteers (~10): Post-survey





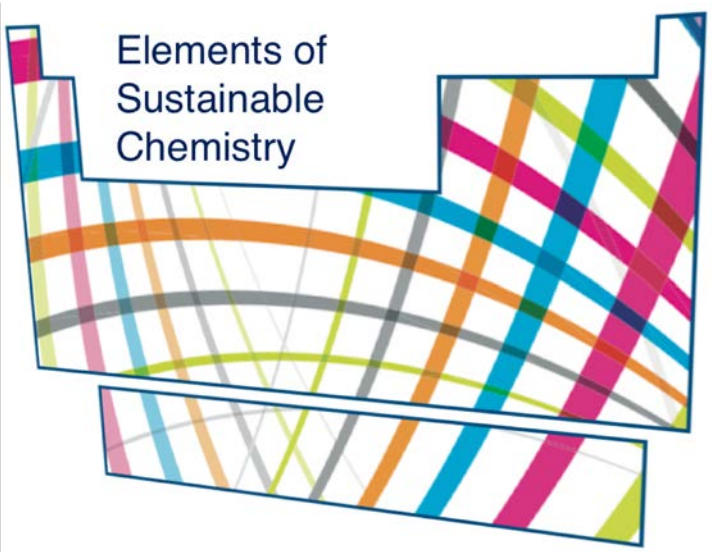


Elements of Sustainable Chemistry (ESC)

Acknowledgements

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

Deakin Science and Society Network
Workshop participants!



New resources website (Nov 2019)
www.eschemistry.org