

Addressing the Sustainable Development Goals in Schools with Chemistry Education

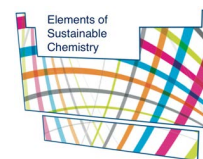
Seamus Delaney

Deakin STEM Ed Conference 2021

Elements of Sustainable Chemistry (ESC) eschemistry.org

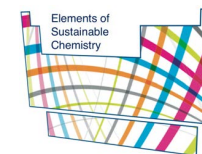
School of Education, Deakin University, Victoria @delaneysw

Deakin University CRICOS Provider Code: 00113B



Acknowledgement of Country

I join you in this conference today from the lands of the Wurundjeri people, First Nations people and Traditional Custodians of the Country on which I live and work and recognise their continuing connection to land, waters and culture. I pay respect to their Elders past, present and emerging.



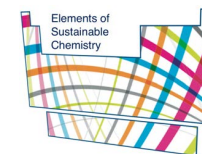
Today's workshop

What we are not doing today

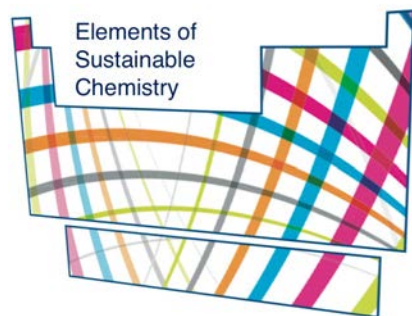
- Hands-on practical activities (so no personal protective equipment required 😊)

What we will cover

- Introduction to systems thinking / integrated learning of chemistry
- Examples of SDGs in Chemistry education
- Mapping SDGs to secondary chemical science topics
- Resources to implement SDG-focused practical activities in schools



Elements of Sustainable Chemistry (ESChemistry.org)



Who we are

- Interdisciplinary, practice-oriented research hub of chemists and chemistry educators

What do we do

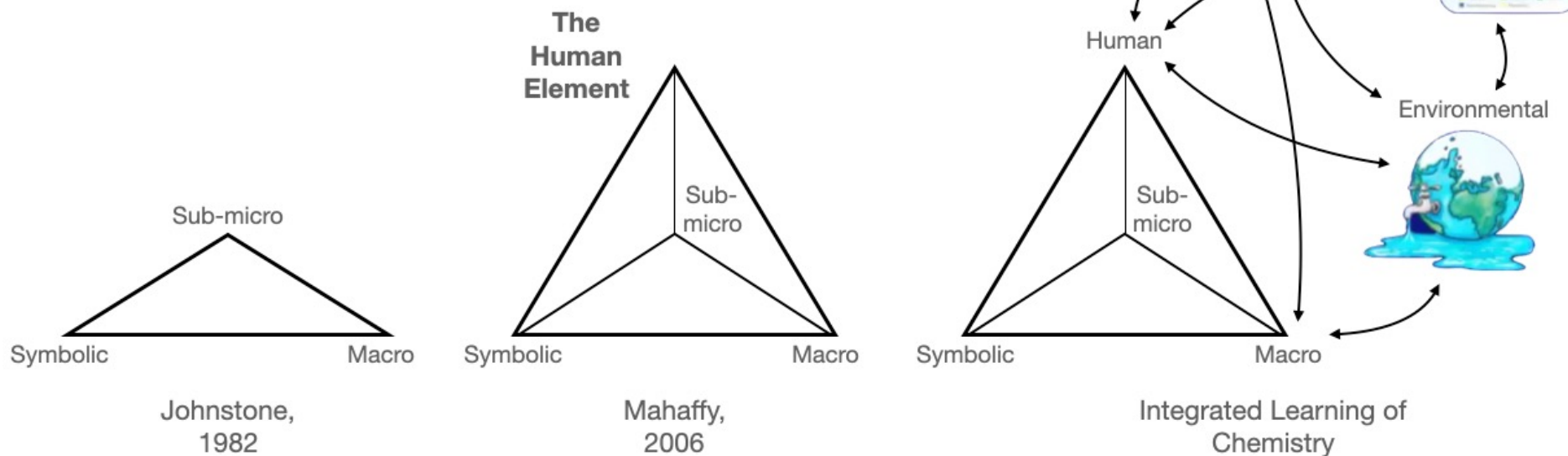
- Recognise the **material basis of society** as a core element of sustainability challenges
- Educate about the molecular basis of sustainability using **systems thinking**
- Support teachers with **professional learning**
- **Co-design** T&L activities for classrooms
- Provide systems thinking oriented, **practical activities** that directly address sustainability



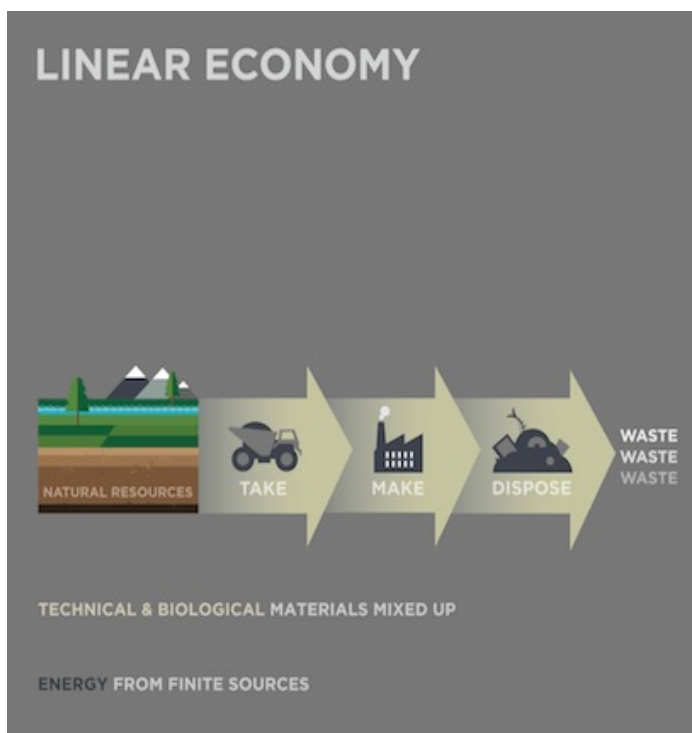
Integrated Learning of Chemistry

*“We cannot fail to recognise the **untenable disconnect** between our current learning objectives and the types of chemical understandings and ways of thinking that our students need to analyse critically and productively to help address the **global challenges** we face”*

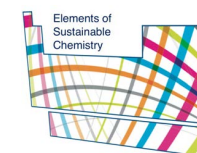
(Talanquer et al., 2020, p. 2697)



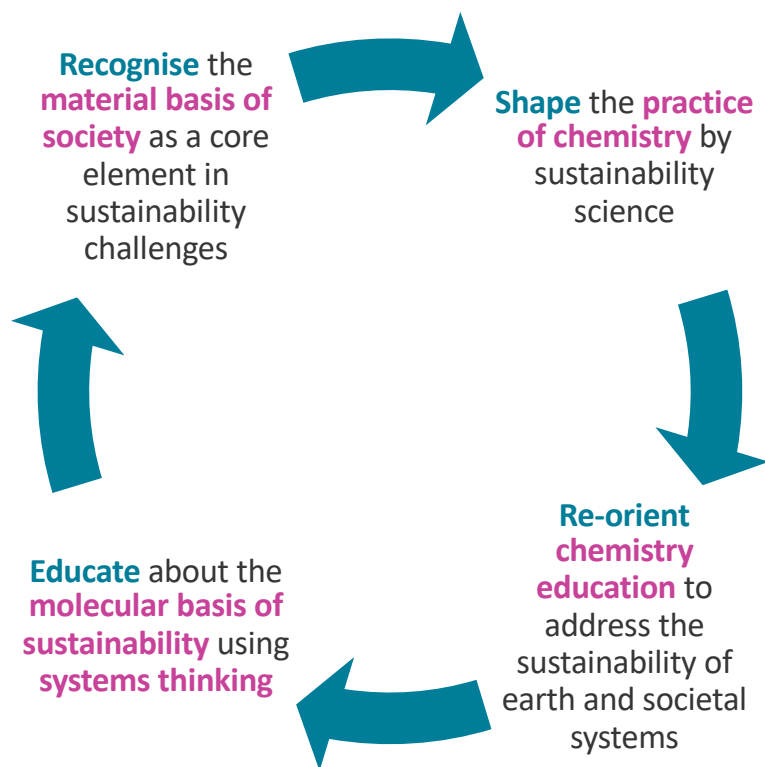
The Linear and Circular Economy



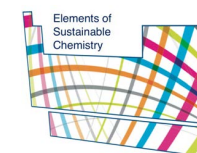
<https://www.ellenmacarthurfoundation.org/our-work/activities/new-plastics-economy>



Systems Thinking in Chemistry Education



SUSTAINABLE DEVELOPMENT GOALS



Mahaffy, P. G., Matlin, S. A., Whalen, J.M. & Holme, T. A. (2019). Integrating the Molecular Basis of Sustainability into General Chemistry through Systems Thinking. *Journal of Chemical Education*. 96(12), 2730-2741. Doi: 10.1021/acs.jchemed.9b00390

Systems Thinking in Chemistry Education

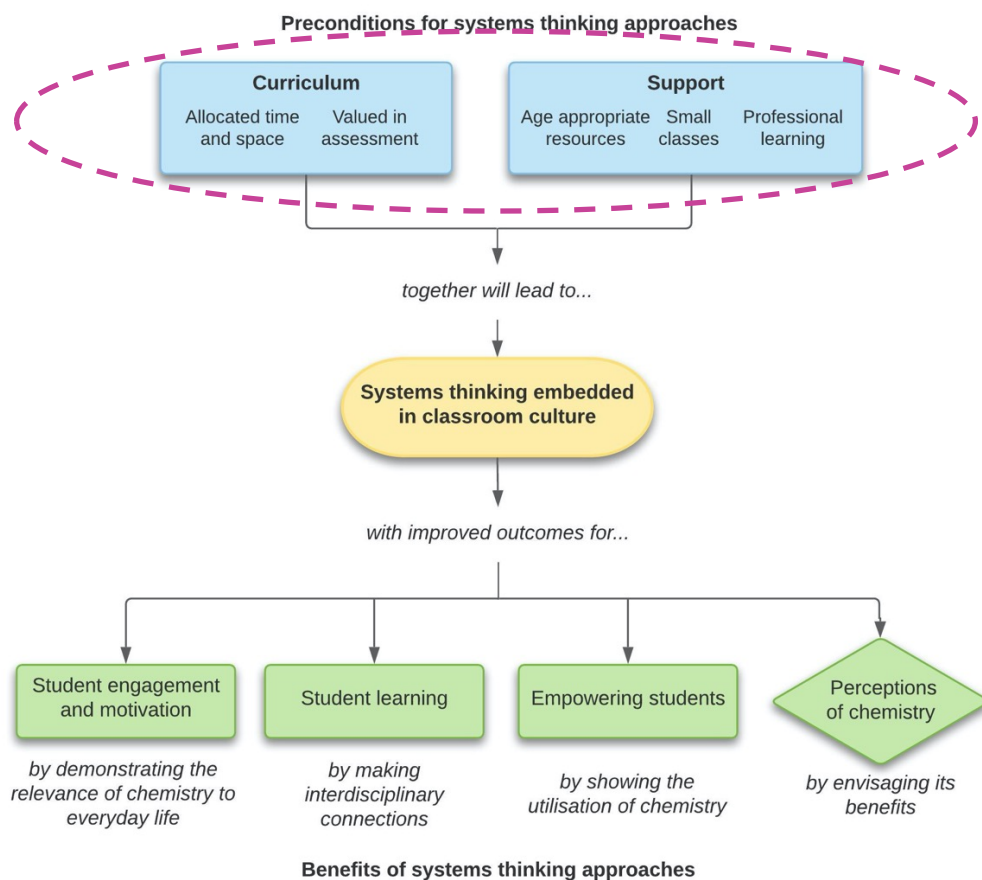
Reductionist / Analytical / Elaborative cognitive processes

- Focussed on the **parts**
- **Bottom-up**
- **Categorising** objects/items
- **Field-independent**: Focussed on how the properties of an object cause a behaviour/change
- Learning facts in **isolation, stepwise** approach
- **“Active”** behaviour in the learner – questioning/dialogue about individual parts of a problem

Systems / Holistic cognitive processes

- Focussed on the **whole**
- **Context-driven**
- **Interrelationships** between objects/items
- **Field-dependent**: Focussed on how the **interaction of object and context** results in a change in an object's behaviour
- Learners **construct an ‘overall picture’** before trying to solve a problem
- **“Passive”** behaviour in the learner – need to put pieces together before approaching the teacher

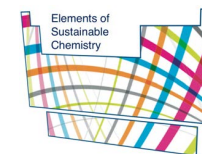
Embedding systems thinking in the classroom



Embedding systems thinking in classroom culture

- Pre-conditions identified in semi-structured interviews with secondary and tertiary chemistry educators

Delaney, S., Ferguson, J.P. and Schultz, M. (2021). Exploring opportunities to incorporate systems thinking into secondary and tertiary chemistry education through practitioner perspectives, *International Journal of Science Education*, DOI: 10.1080/09500693.2021.1980631



United Nations Global Goals for Sustainable Development (SDGs)

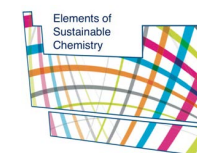


SUSTAINABLE DEVELOPMENT GOALS

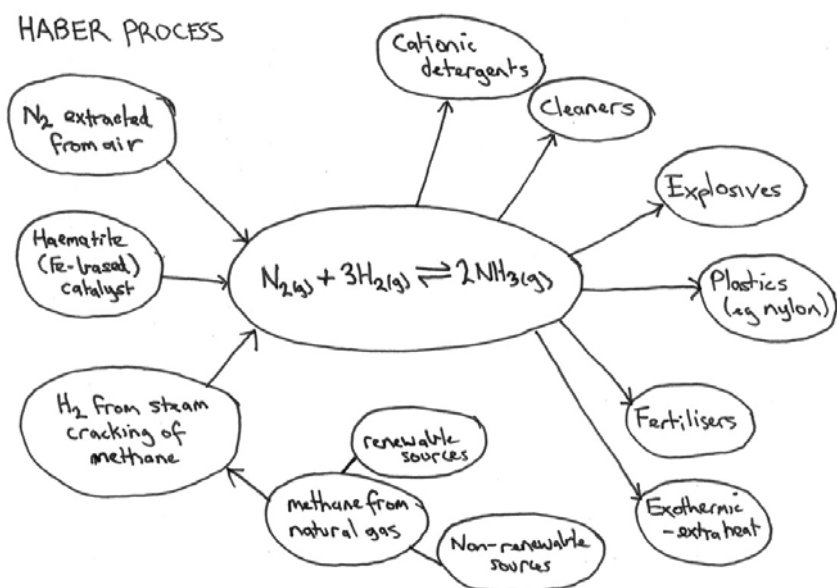
17 GOALS TO TRANSFORM OUR WORLD



And... as a framework to **evaluate** the scientific, ethical, social and environmental issues in chemistry contexts

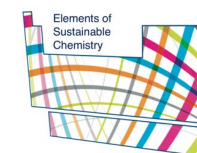


Evaluating systems thinking - Systems Maps



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

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



The “central learning outcome” of chemistry...

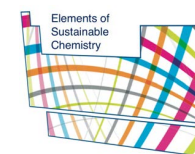
“Chemicals have benefits and hazards, and **these must considered together**” (p. 499)

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

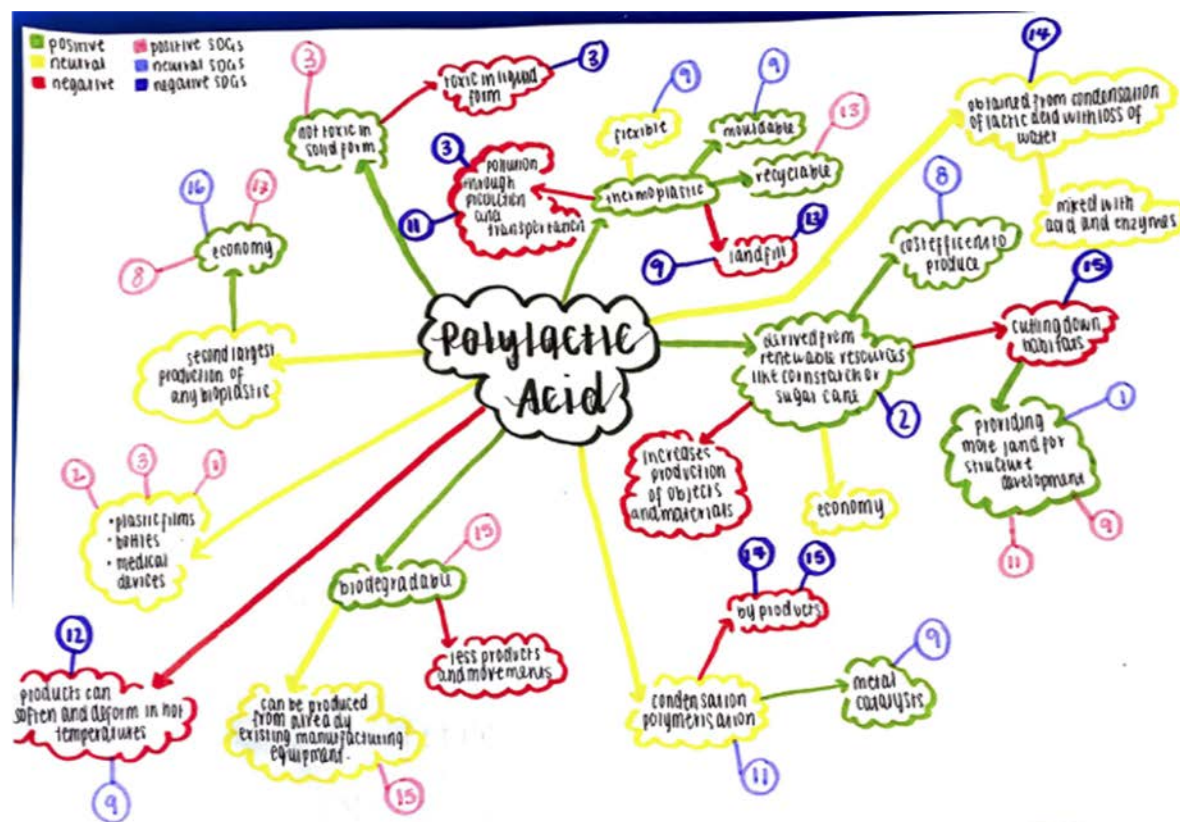
(Holme and Hutchison, 2018)

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

Holme, T.A., & Hutchison, J. E. (2018). A Central Learning Outcome for the Central Science. *Journal of Chemical Education*, 95, 499-501.

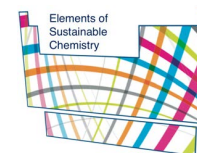


Evaluating systems thinking - Systems Maps



- Real-world contexts of chemical processes
- Connections to UN Global Goals for Sustainable Development (SDGs)

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*, 96, 2968-2974.



CHEMISTRY
EDUCATION
ASSOCIATION

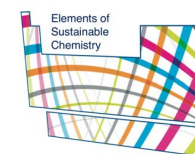


United Nations Global Goals for Sustainable Development (SDGs)



1. Medicines, local solar energy
2. Improved, adapted agrochemicals
3. Drug design, healthcare products, pollution control
4. Courses in green chemistry and environmental sciences
5. Equal gender chances among chemists
6. Water regeneration and purification
7. Photoelectrochemistry, new batteries
8. Recycling, circular economy, long-living products
9. Research on pure and applied chemistry
10. IUPAC networks to underdeveloped regions

Tundo, P. and Griguol, E. (2018). Green Chemistry for Sustainable Development, *Chemistry International*, 40 (1), 18-24.

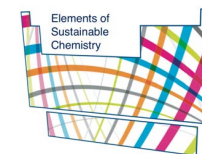


United Nations Global Goals for Sustainable Development (SDGs)



11. Novel materials for buildings, bridges, streets, cultural heritage conservation
12. Sustainable manufactures and waste minimization
13. Innovative solar energy systems
14. Marine chemistry
15. Sustainable use of fossils and forests, renewable resource exploitation
16. Support to the Organization for the Prohibition of Chemical Weapons (OPCW)-goals
17. Cooperation with UN, OECD, OPCW, UNESCO and other scientific organizations

Tundo, P. and Griguol, E. (2018). Green Chemistry for Sustainable Development, *Chemistry International*, 40 (1), 18-24.



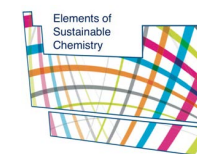
United Nations Global Goals for Sustainable Development (SDGs)



- *How can chemistry help society achieve this sustainable development goal?*
- *How could teachers and students learn and contribute to achieving this goal in the chemistry classroom, VCE or lower secondary*

Shared google doc link with suggestions made by participants from previous conferences

- <https://bit.ly/2YQhuXC>
- We'll keep it live afterwards – feel free to come back to it



Let's have a go ourselves



Plastics

<https://bit.ly/3AJRqej>



Fertilisers

<https://bit.ly/3LL5sJ5>

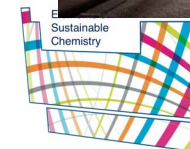


Concrete

<https://bit.ly/3FLA3OF>



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-oriented practical activities



Making an aluminium-air battery



Turning copper coins 'silver' and 'gold'



Copper crystals growing on aluminium sheet



Carbon rod electrolytic writing



Periodic Table element sort and gallium

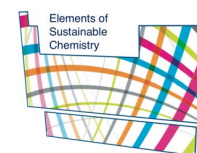
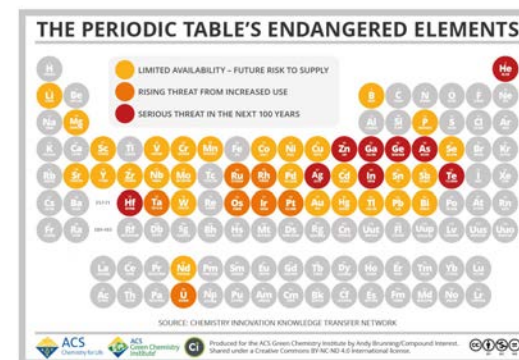


Iodine writing and fingerprints

Practical activities highlighting endangered elements

All resources available on website – eschemistry.org

- Zinc, copper, aluminium, gallium, iodine and others



Endangered Elements poster

SAVE ME FROM EX-ZINC-TION

This white powder shows up in everything from sunscreens to solar cells to nuclear reactors, where it helps prevent corrosion

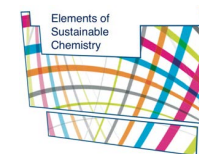


70% of the worlds zinc reserves has been used... 20 years ago!

Endangered Elements Poster

- **Why** are they considered 'endangered'?
- **Where** and **What** are they sourced from?
- **What** are they used for?
- **So what** can we do about it?

- Link three **Sustainable Development Goals (SDGs)** to how these elements to meeting 21st century challenges

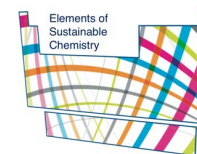


Systems thinking-oriented practical activities

Practical activities highlighting elements

All resources available on website – eschemistry.org

- Mini-thermite reaction - Energy in/out from aluminium processing
 - 3% of global electrical supply used to extract aluminium
 - **Recycling** aluminium uses only 5% of the energy requirements to make new aluminium



Australian
National Commission
for UNESCO



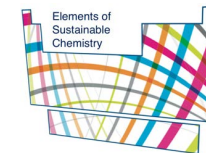
Systems thinking-oriented practical activities

Sustainable Concrete

- Co-designed with researchers from Institute for Frontier Materials, Deakin
- Guided inquiry control of variables (COV) investigation for secondary schools



- Cementous material alternatives
- Fine aggregate alternatives to river sand
- Coarse aggregate alternatives (incl. recycled materials)
- Options for water source



Systems thinking-oriented practical activities

Sustainable Concrete

Setting up the investigation - Seamus' seminar group

3/7

Share

Set background Clear frame

Group 3

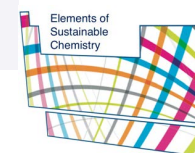
Group Name
Group 3?

What are you keen to try?
Using all recycled materials!

Hint: Each partner should investigate something different

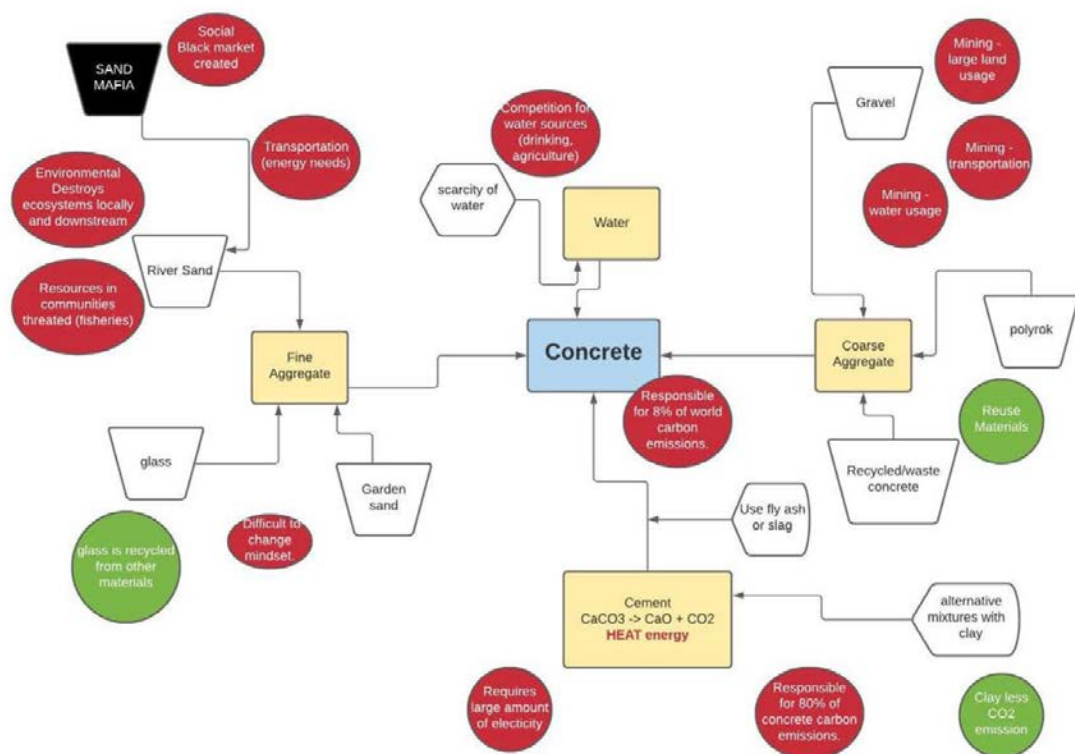
Partner name	What will you keep the same?	What will you change?	What will you measure?	Your research question
Mac	Type of sand (river sand) Cement - OPC Water - Fresh Water The mixture ratio of cement, fine aggregate, water (1:2:1:1)	Type of gravel (normal gravel, waste concrete and polystyrene)	The strength of the concrete pillar	Will the strength of concrete change when using different types of coarse material (normal gravel, polystyrene and waste concrete)?
Roslyn	Type of coarse (gravel) Water - Fresh Water Cement - OPC The mixture ratio of cement, fine aggregate, water (1:2:1:1)	Type of sand (river sand, garden sand, glass sand)	The strength of the concrete pillar	What happens to the strength of the concrete when we change the type of sand used?
Camilla	Type of sand (river sand) Type of water (fresh water) Type of coarse (gravel) The mixture ratio of cement, fine aggregate, water (1:2:1:1)	Type of cement (OPC, 15% clay with OPC, 30% clay with OPC)	The strength of the concrete pillar	What happens to the strength of the concrete when we change the type of cement used?
Daniel	Type of sand (river sand) Type of cement (OPC) Type of coarse (gravel) The mixture ratio of cement, fine aggregate, water (1:2:1:1)	Type of water (rain water, fresh water, deionised water?, toilet water)	The strength of the concrete pillar	What happens to the strength of the concrete when we change the type of water used?
	Controlled variables	Independent variable (IV)	Dependent variable (DV)	What happens to (DV) when we change (IV)?

Delaney, S. and Schultz, M. (2021). Investigating sustainable chemistry - a control-of-variable guided inquiry practical activity making sustainable concrete, *LabTalk* (Issue 4, 2021).



Systems thinking-oriented practical activities

Sustainable Concrete



Competing demands for clean water for drinking, agriculture, industries.



Mining of sand polluting/destroys water ways
Increasing ocean acidification caused by increasing levels of carbon dioxide in atmosphere.



Finding alternatives to concrete, cement, aggregate. Use slag, fly ash or calcined clay in cement



Manufacturing cement responsible for 8% of all carbon emissions. Potential to carbon capture and store back in concrete.



Used to make buildings, bridges, roadways. Innovation in using different materials



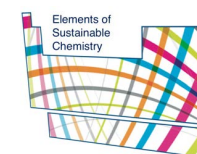
Using waste concrete and alternative products which can be reused and recycled back into coarse aggregate.



Potential to reduce indirect CO2 emissions through renewable electricity.



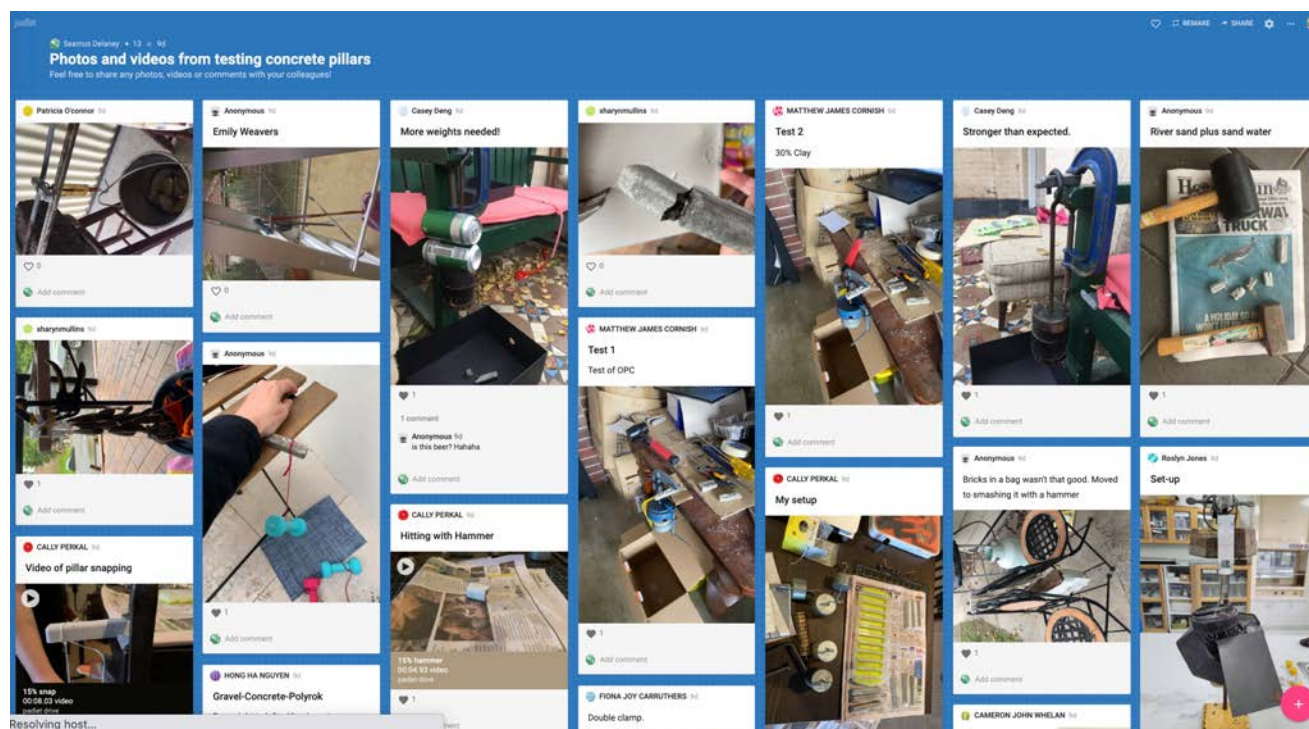
Concrete building infrastructures that generates employment, economic growth.



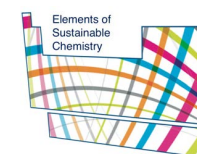
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Systems thinking-oriented practical activities

Sustainable Concrete



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Systems thinking-oriented practical activities

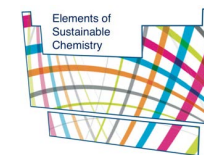
Sustainable Concrete

The screenshot shows a PowerPoint presentation with the following content:

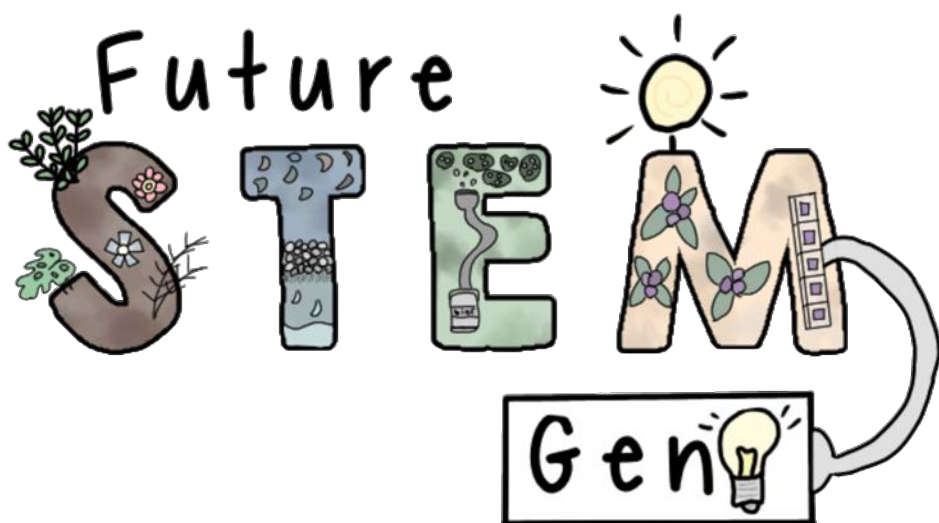
- Title:** Testing and Comparing Concrete Data Using Weights and Hammers
- Introduction:** How can we make concrete more sustainable? In this experiment, we tested the strength of concrete by replacing the fine aggregate, cement and coarse aggregate.
- Method:** Change one element when creating concrete. Sand - River, garden and glass. Cement - OPC, 15% clay and 30% clay. Aggregate - Gravel, concrete and polyrok.
- Results:** Four bar charts showing the effect of different variables on concrete strength:
 - Effect on type of cementitious material on strength of concrete.
 - Effect on type of fine aggregate on strength of concrete.
 - Effect on type of coarse aggregate on strength of concrete.
 - Effect on type of water on strength of concrete.
- THE HARD FACTS ABOUT SUSTAINABLE CONCRETE:** A central image showing various concrete samples and testing equipment.
- Discussion:** Polyrok is very fragile comparing to other but very light so it can be useful to some separation rather than making big poles in construction. Do not use rainwater if you want your concrete strong !!!
- Conclusion:** River sand and OPC and gravel can be the best combination in terms of the strength. Glass sand, 30% clay and polyrok can be a great combination of environmentally friendly concrete, probably our future concrete !!!

Home Group 6

Delaney, S. and Schultz, M. (2021). Investigating sustainable chemistry - a control-of-variable guided inquiry practical activity making sustainable concrete, *LabTalk* (Issue 4, 2021).



Systems thinking-oriented practical activities

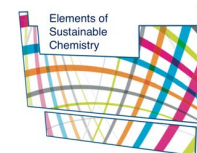


Practical activities highlighting future energy/living challenges

Future STEM Gen project

- Local energy for global futures (dye-sensitised solar cells, bio-algae)
- Smart gardens
- Water filtration (primary science)

<https://www.futurestemgen.education/>



Australian
National Commission
for UNESCO



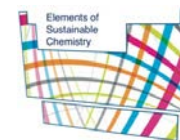
Systems thinking-oriented practical activities

Authentic real-world contexts with practical activities

- Longer, group- or class-based 'design' projects
- Teachers might ask the 'question' but potential for students **develop the problem**

Resources for design-based practical activities

- Beyond Benign
 - <https://www.beyondbenign.org/>
- National Science Foundation Centre for Sustainable polymers
 - <https://csp.umn.edu/labs/>



Systems thinking-oriented practical activities

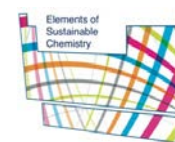


featured lessons



Lots of great teacher/student resources for different year levels (K-12) and topics

- US-based, so curriculum links are USA
- Open-source, Creative Commons
- MS Word documents



Systems thinking-oriented practical activities

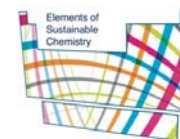


featured lessons



Some of my design/system thinking favourites

- Life cycle analysis of polystyrene and mushroom-based (mycelium) packaging materials
- Recycling polylactic acid
- 'Sharklet' anti-microbial surfaces



Humanising Chemistry Education

Name:

Consider this question at each level of chemistry (using drawings if needed)

Prompting question: Aluminium is a fantastic metal that has allowed humans to take to the skies... in more ways than one. Aluminium as a building material can be used to construct planes that are strong, stable in harsh environments, and importantly, lightweight. Aluminium powder however is dangerously explosive, making it useful as an additive to rocket fuel. When the fuel burns, the aluminium powder reacts with oxygen to produce aluminium oxide... and a LOT of energy.

Explain, using your understanding of factors that vary the rate of a chemical reaction, why substances such as aluminium can react so differently depending on their form.

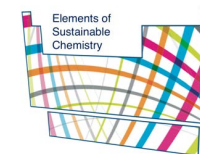
Macroscopic level: What can we see, observe? How can this be represented?

Human level: How is this chemistry relevant to society? Impact?

Sub-microscopic level: What's *can't* we see, observe (molecules, ions, electrons)? How can this be represented?

Symbolic level: How can represent what is happening using the language of chemistry?

- Drawing **conceptual connections** across the four levels of chemistry
 - Macro
 - Sub-micro
 - Symbolic
 - **Human**



Acknowledgements

Madeleine Schultz, Joe Ferguson, Jerry Lai, Lisa Chiavaroli

IUPAC STCS 2030+ Task group

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Tom Holme (Iowa State University)

Mary-Kay Orgill (University of Nevada, Las Vegas)

