

Supplementary Information

Supporting Information for Using systems Maps to Visualise Chemistry Processes: Practitioner and Student Insights

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S1. Survey instrument

Pre-survey

Please answer the questions below. Your responses are entirely confidential.

Identification code of student: _ _ _ _

1. What is your gender?
2. Please indicate your level of agreement with the following statements:
(Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree)
 - a) I find chemistry interesting.
 - b) I find chemistry relevant to my everyday life.
 - c) I think chemistry is a driver for global change.
3. Please give reasons for your responses to a), b) and c) above.
4. Please indicate your level of agreement with the following statements:
(Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree)
 - a) Sustainability is important to me.
 - b) I know what sustainability means in relation to chemistry.
5. In my own words, sustainable chemistry means...
6. Why do you think sustainable chemistry is important? (Choose all that apply.)
 - To conserve energy
 - To protect the environment
 - To protect/improve human health and safety
 - To improve chemistry research
 - To make experiments safer
 - To improve chemistry education
7. The United Nations has agreed 17 Sustainable Development Goals. How much do you think chemistry can contribute to working towards each of these goals?
(a lot, a moderate amount, not at all, I don't know)

GOAL 1: No Poverty

GOAL 2: Zero Hunger

GOAL 3: Good Health and Well-being

GOAL 4: Quality Education

GOAL 5: Gender Equality

GOAL 6: Clean Water and Sanitation

GOAL 7: Affordable and Clean Energy

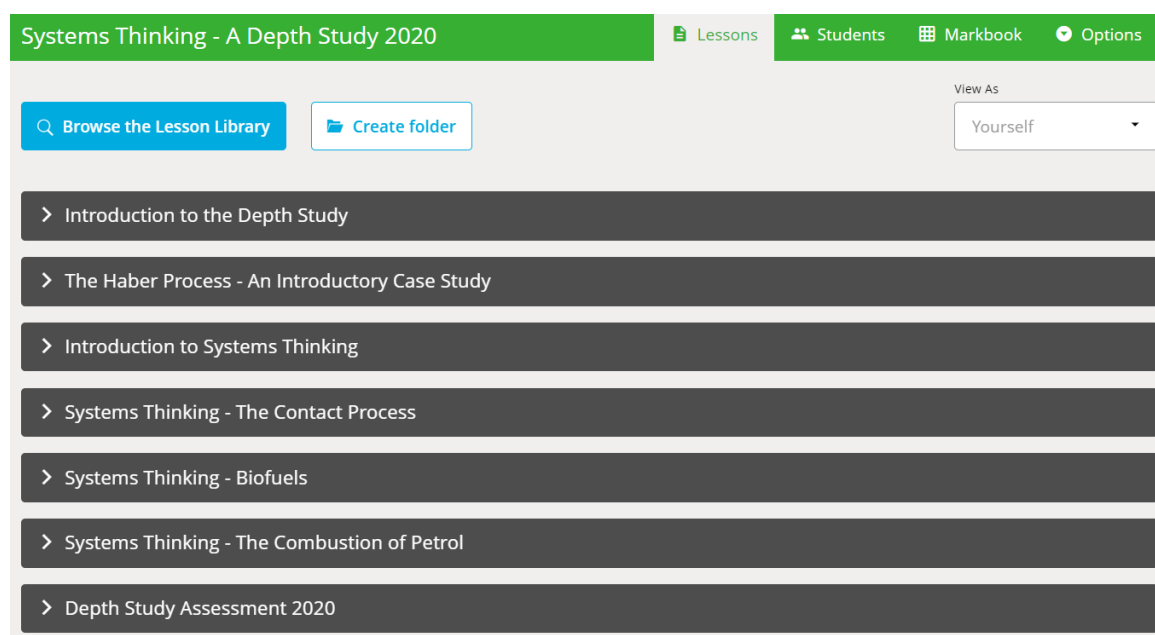
GOAL 8: Decent Work and Economic Growth
GOAL 9: Industry, Innovation and Infrastructure
GOAL 10: Reduced Inequality
GOAL 11: Sustainable Cities and Communities
GOAL 12: Responsible Consumption and Production
GOAL 13: Climate Action
GOAL 14: Life Below Water
GOAL 15: Life on Land
GOAL 16: Peace and Justice Strong Institutions
GOAL 17: Partnerships to achieve the Goal

8. Please indicate your level of confidence in each of the following processes. I am confident in:
(Extremely confident, Moderately confident, Slightly confident, Not at all confident)
- a) Realising that problems have multiple parts
 - b) Analysing multiple aspects of a problem
 - c) Seeing links between parts of a problem
 - d) Describing how the links between parts of a problem change over time
 - e) Solving a problem by looking at how the parts work together
9. Have you ever heard of Systems Thinking?
10. If you have heard of Systems Thinking, please write in a couple of sentences what it means to you.

S2. Vignette 1: Details of Classroom Teaching Approach.

As per NSW syllabus requirements [1, 2], the Depth Study met the mandatory Working Scientifically skills of Questioning and Predicting, and Communicating, as well as Conducting Investigations, Processing Data and Information, Analysing Data and Information and Problem Solving. In addition, the Depth Study developed two Knowledge and Understanding outcomes: “explains the characteristics of equilibrium systems, and the factors that affect these systems” and “describes and evaluates chemical systems used to design and analyse chemical processes”.

The content of the Depth Study was delivered via a combination of teacher-led presentations and the online education program Stile, utilizing teacher-developed modules. The lesson plan for the 2020 iteration is shown below; further detail is available in [3]. Four chemical processes were selected for inclusion: the Haber Process, the Contact Process, synthesis and evaluation of biofuels and the production and combustion of petrol. These topics were considered suitable for generating student interest in systems thinking because they are all extremely important industrially, and also have significant societal impacts with which most students are familiar. The sequence was chosen to move from more simple to more complex chemical reactions and systems maps.



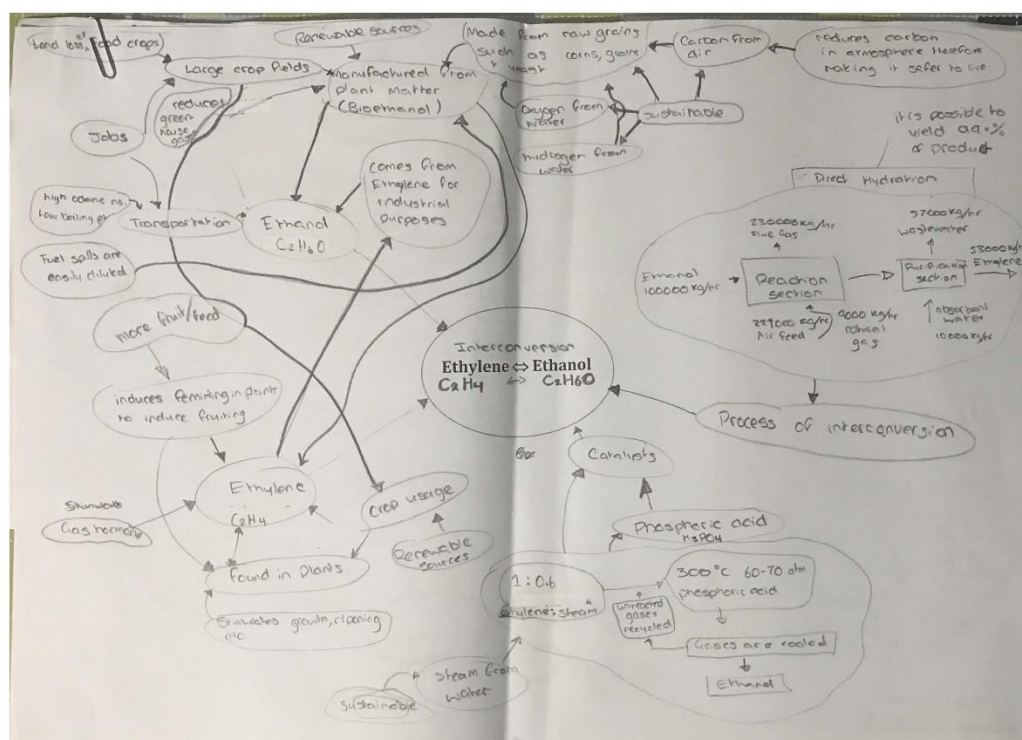
Online lesson plan for 2020 iteration of systems thinking Depth Study, showing the four chemical processes selected.

The three systems thinking modules shown above consisted of a series of lessons, each having the general structure of

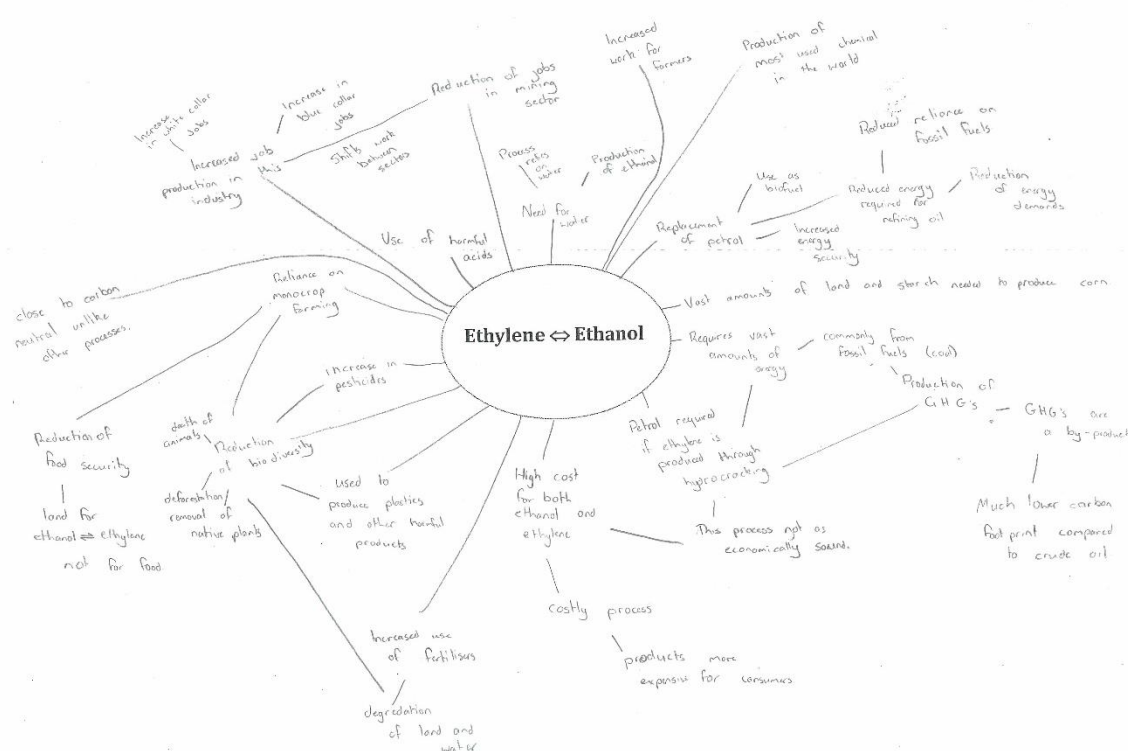
- (i) introduction to the system,
- (ii) organization of the associated information of the system into a systems map,
- (iii) evaluation of the systems map using SDGs, and
- (iv) research by the students into areas of the system where current scientific research aimed to improve SDG outcomes.

The first systems map was drawn collaboratively as a whole class exercise and students worked in small groups for subsequent maps. The assessment tasks were performed individually.

S3. Vignette 1: Further Examples of Student-Generated Maps



This map focusses on chemistry and production aspects of the two compounds and their interconversion on the right hand side. Properties and applications of the two substances are on the left hand side, and sustainability aspects of bioethanol can be seen at the top.



This map is less structured and lists many negative aspects of this chemical process along with a few sustainability issues.

S4. Vignette 2: Details of Classroom Teaching Approaches.

T2 first presented students with information about acids and bases in the environment. Students were then shown the teacher-generated systems map that we had previously published [3] and asked to draw mind maps of one of those issues.

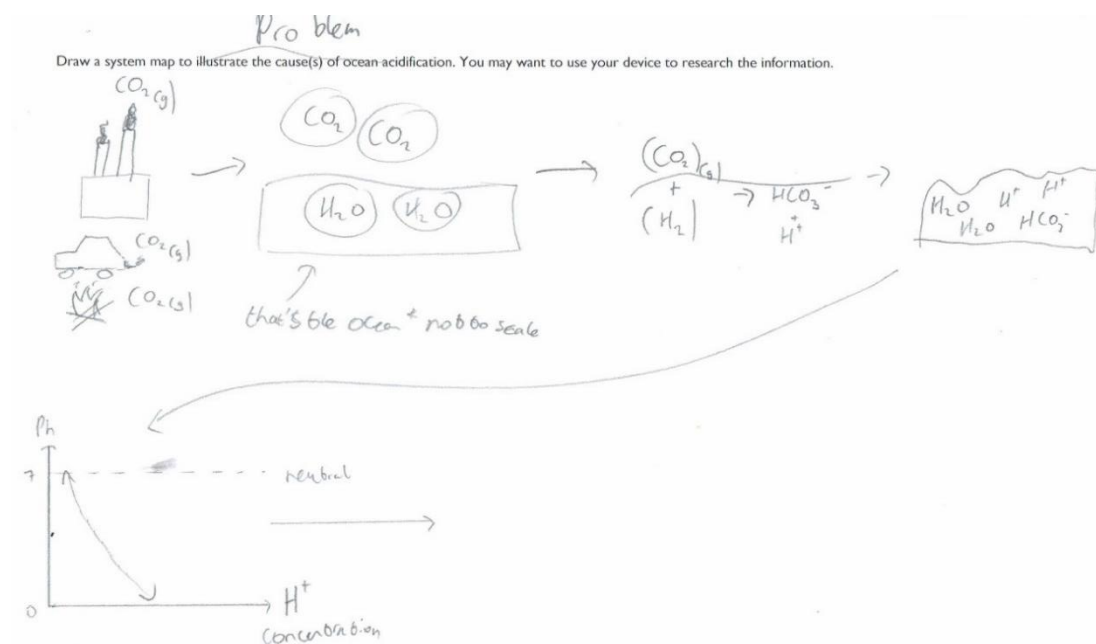
The second part of the task asked students to evaluate the maps according to the SDGs, labelling the map with the corresponding SDG number and classifying the impacts as positive, neutral or negative.

T3 first introduced her students briefly to systems thinking as a holistic approach to analysis, incorporating relationships, inputs, and intended and unintended impacts. She showed a systems map that she had made, that looked at plastics from crude oil to final disposal.

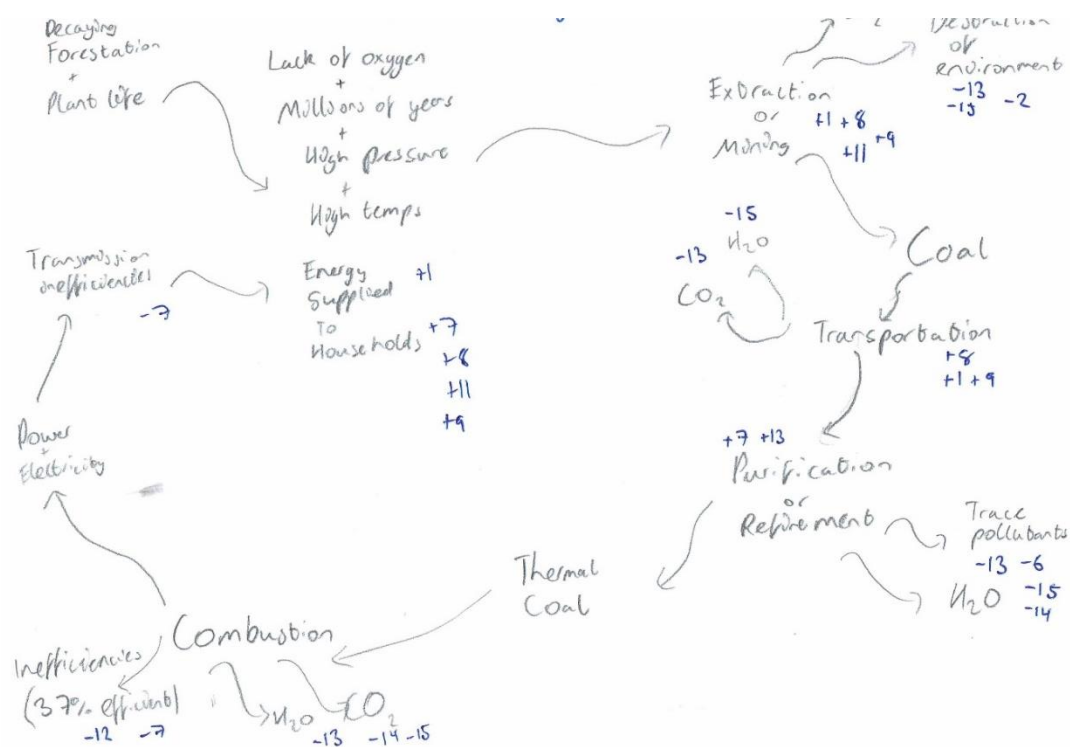
T4 presented the students two videos, one about systems thinking from the American Chemical Society's Green Chemistry Institute (<https://www.youtube.com/watch?v=x7vrDRBD8kM>) and one about N95 masks (<https://www.youtube.com/watch?v=eAdanPfQdCA>). He then gave the students information about systems maps, using our published example [3].

S5. Vignette 2: Further Examples of Student-Generated Maps

T3: Pre and post from a single student, showing increased ability to form connections and and ST skills.

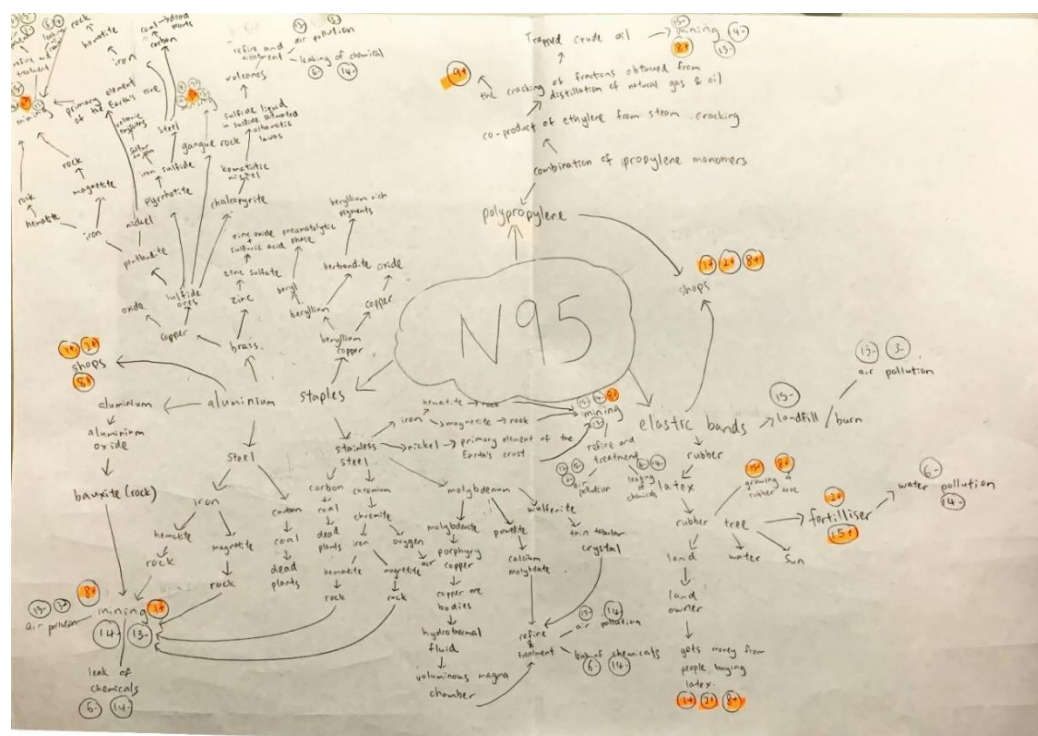


In this map, the student has denoted the chemical reaction across the top in multiple stages and shown the transfer of gases from industrial outputs to the ocean, followed by the formation of carbonic acid. The diagram at the bottom illustrates the relationship between pH and hydrogen ion concentration, and the link indicates that increases CO₂ concentration results in lower pH.

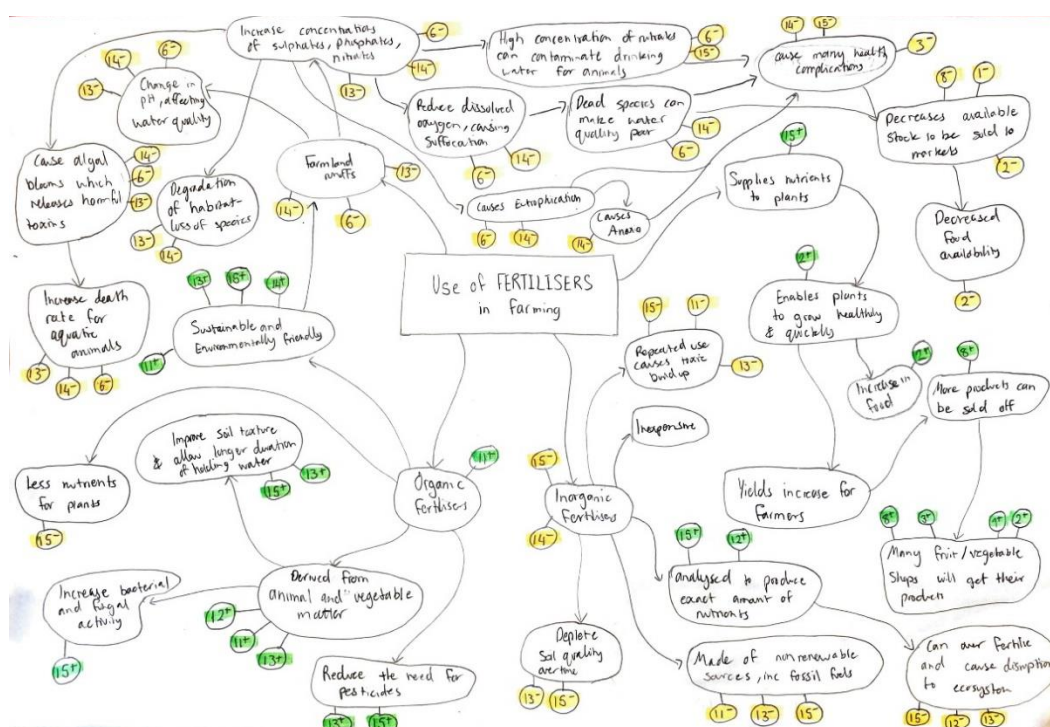


This map has less focus on the chemical reaction and includes more societal aspects, including several uses of energy. Positive and negative impacts on specific SDGs have been listed.

T4: Student-drawn systems map for N95 masks from T4, annotated with SDG numbers.

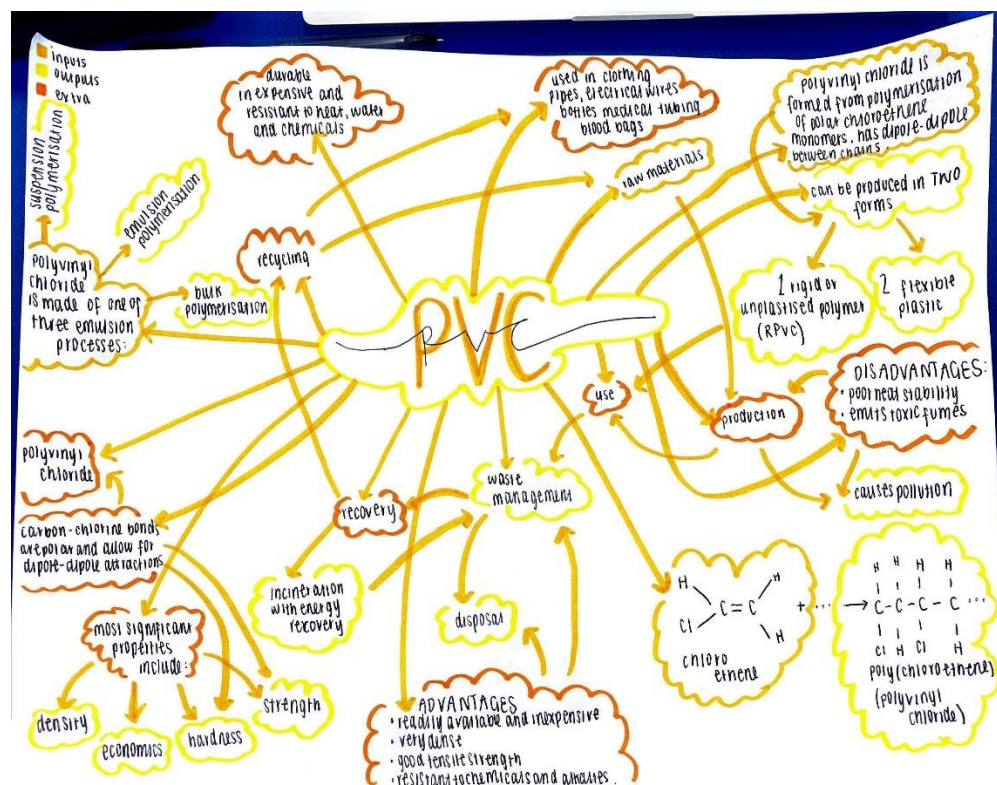


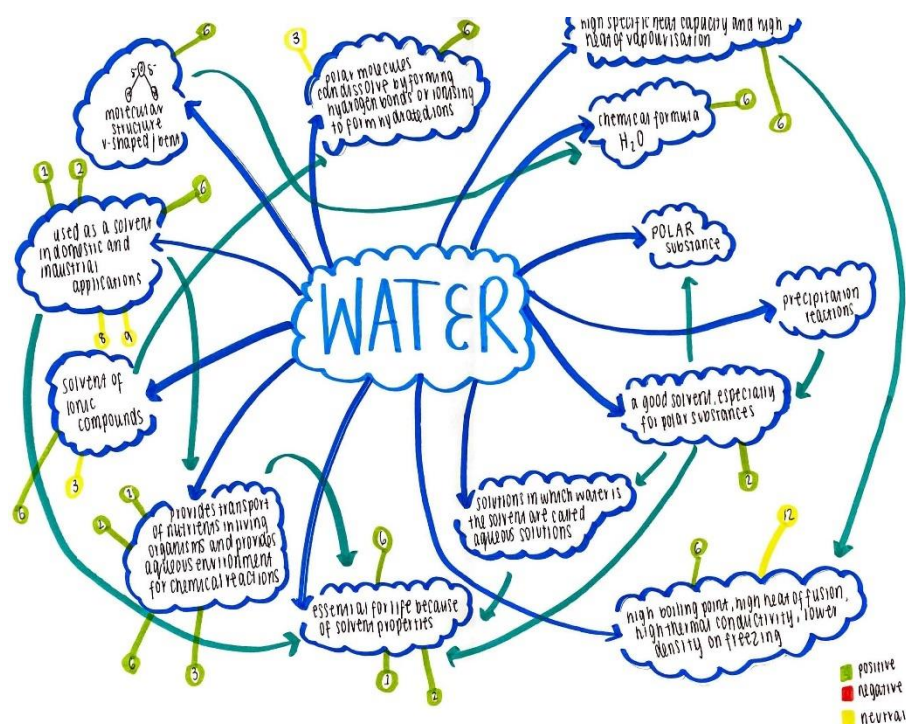
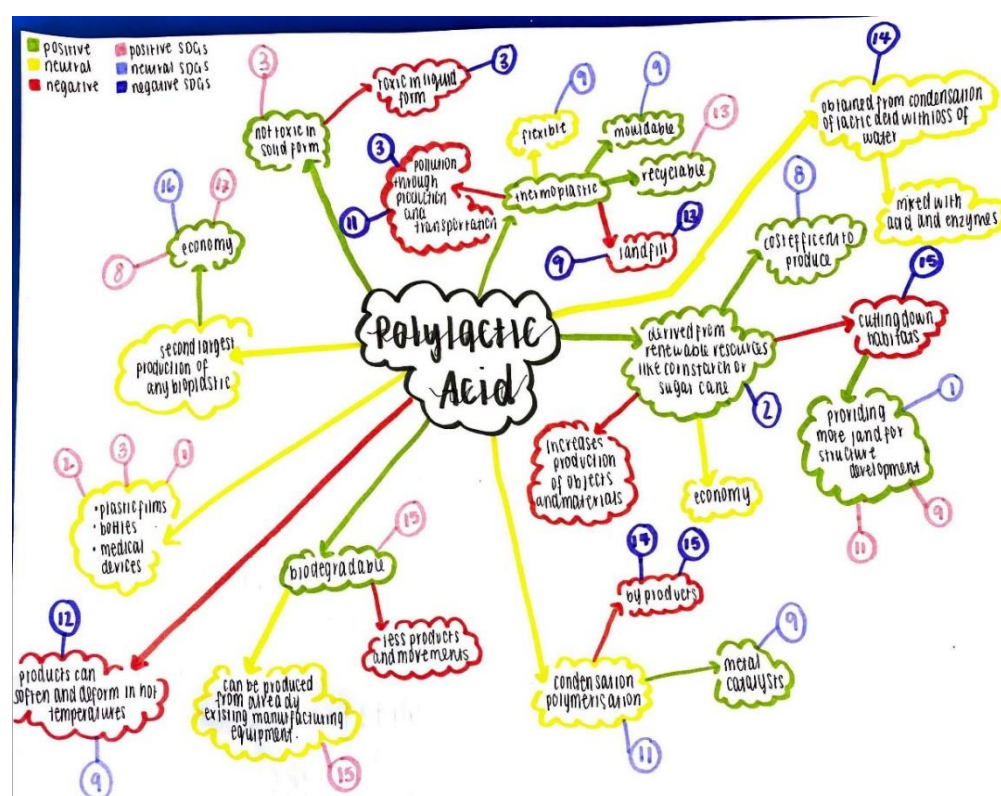
Careful inspection shows that some of the entries are not relevant or scientific; this student appears to have included words from other subjects such as geology.



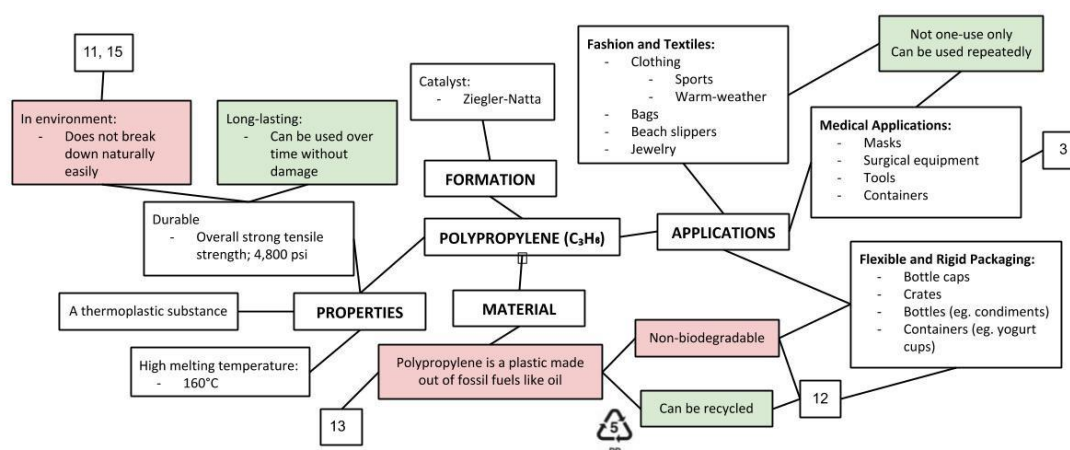
This map is organized in four sections: run-offs (and associated environmental issues) shown across the top, reasons that fertilizers are used on the right, and organic and inorganic fertilizers at the bottom. Multiple SSIs farming are included but there are few cross-links.

T5: Three maps from a single student showing ST development over the course of the year.





T6: Student-drawn systems map for polypropylene from T6, highlighted to show processes that have positive or negative impacts on sustainability.



It can be seen that this student addressed chemical factors (type of catalyst) along with multiple applications of the polymer. However, the properties were not connected to the applications, which is a missing link that may be developed through further classroom discussions.

S6. References

1. NSW Education Standards Authority. Science Stage 6. Available online: <https://educationstandards.nsw.edu.au/wps/portal/nesa/11-12/stage-6-learning-areas/stage-6-science> (accessed on May 31 2022).
2. NSW Education Standards Authority. Depth Studies: Year 11 and 12. Available online: <https://educationstandards.nsw.edu.au/wps/portal/nesa/11-12/stage-6-learning-areas/stage-6-science/chemistry-2017/depth-studies> (accessed on 31 May 2022).
3. Eaton, A. C.; Delaney, S.; Schultz, M. Situating Sustainable Development within Secondary Chemistry Education via Systems Thinking: A Depth Study Approach. *J. Chem. Ed.*, **2019**, *96*, 2968–2974. doi: 10.1021/acs.jchemed.9b00266