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Scaffolding School Pupils' Scientific Argumentation with Evidence-Based Dialogue Maps

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Abstract. This chapter reports pilot work investigating the potential of Evidence-based Dialogue Mapping to scaffold young teenagers' scientific argumentation. Our research objective is to better understand pupils' usage of dialogue maps created in Compendium to write scientific explanations. The participants were 20 pupils, 12-13 years old, in a summer science course for "gifted and talented" children in the UK. Through qualitative analysis of three case studies, we investigate the value of dialogue mapping as a mediating tool in the scientific reasoning process during a set of learning activities. These activities were published in an online learning environment to foster collaborative learning. Pupils mapped their discussions in pairs, shared maps via the online forum and in plenary discussions, and wrote essays based on their dialogue maps. This study draws on these multiple data sources: pupils' maps in Compendium, writings in science and reflective comments about the uses of mapping for writing. Our analysis highlights the diversity of ways, both successful and unsuccessful, in which dialogue mapping was used by these young teenagers.

1 Why is it so hard to argue scientifically?

Within the school science education research community, there is increasing concern about the weakness of pupils' scientific thinking skills, particularly about the quality of argumentation. Teaching how to argue with evidence is essential for pupils to understand how scientific knowledge is constructed and validated. In many countries like the United Kingdom, the emphasis of the science curricula is shifting towards 'scientific literacy'. Teachers are now required to develop pupils' capabilities to engage with science-based technology and the socio-scientific issues they will encounter outside school, rather than just on grounding in knowledge or a preparation for a scientific career. As scientific issues continue to dominate public policy that impacts our lives (e.g., food safety, environment, genetic engineering) citizens need to have the skills to assess the reliability of information, the soundness of arguments, and the ethical implications. In order to be "scientifically literate" pupils need to know how to

put together arguments coherently (Hodson, 2003). Teachers need to equip young teenagers with the ability to evaluate claims about science in the media.

Learning “scientific argumentation”, which is defined by Suppe (1998) as the co-ordination of evidence and theory in order to support or refute an explanatory conclusion, model or prediction, is not an easy task for pupils. They find it difficult to apply their knowledge to construct scientific explanations. Recent studies show that many pupils are very poor at connecting data and theory in order to validate arguments (Kuhn, 1991; Means and Voss, 1996; Hogan and Maglienti, 2001). Schwarz and Glassner (2003:232) observed that pupils do not know how to connect, to check or challenge arguments and apply them in further activities. *“In science, children ‘see’ arguments; however they are ‘paralytic’ concerning the argumentative activities of which these scientific arguments may be the subject”*.

Scientific argumentation skills do not come naturally. Kuhn’s studies (1991) motivate the view that presenting controversial socio-scientific issues for debate in the classroom is not sufficient on its own to foster good argumentation skills (Kuhn, 1991; Newton, Driver, and Osborne, 1999; Rider and Thomason, chapter X). Teachers need to assist pupils in making their thinking explicit, helping them to clarify and shape their reasoning around the norms and criteria which underpin scientific discourse (Hogan and Maglienti, 2001:683). Simon, Erduran and Osborne (2002) emphasise scientific reasoning is a special form of discourse that needs to be developed and appropriated by pupils through suitable tasks, and through “structuring and modelling”. In order to help pupils scaffold scientific argumentation teachers need to show how to set out strong components and establish good connections.

A good scientific argument is constituted by both domain knowledge and argumentative knowledge. Simon et al(2002:2) point out *“scientific rationality requires a knowledge of scientific theories, a familiarity with their supporting evidence and the opportunity to construct and/or evaluate their inter-relationship.”* Means and Voss (1996) also highlight that subject knowledge and personal experience to elaborate arguments are two important components for argumentation. In order to argue, pupils need to use both scientific concepts and their own arguing skills to ground their reasoning. The more knowledge is integrated in their arguments, the richer is their argumentation (Schwarz and Glassner, 2003:230).

This pilot study is the first in a long term research programme to investigate how approaches like dialogue mapping can augment pupils’ scientific reasoning, and critical thinking more broadly. This exploratory work analyses the potential of using dialogue mapping to scaffold young pupils’ scientific argumentation. In this context, by scaffolding we mean constructing scientific argumentation graphically through a step-by-step process. We are currently framing this inquiry in terms of the following general questions, each of which has many possible sub-issues:

- Scientific knowledge and mapping. As noted, the current interest in deliberation and argumentation that we see amongst researchers and practitioners is driven by the recognition that beyond a good understanding of the domain, pupils also need the skills of being able to communicate and critique in an appropriate way their own reasoning, and that of peers. This question focuses on the interplay between domain and argumentation knowledge: how can each one sharpen the other?

- Scientific writing and mapping. What are the effects of translating between the non-linear graphical languages of maps, and linear presentations in speech or prose? Does translating their own or a peer's speech or writing into a map lead to new insights? What is the effect of creating a dialogue map on derivative written and spoken presentations?
- Cartographic literacy. We know a lot from previous research about the cognitive skills of crafting good concept, dialogue and argument maps: it is hard work, but at its best is satisfying and fosters intellectual rigour. Which of these processes do pupils find easy or hard to attain, and can they be communicated in more age-appropriate, multimodal/media ways?
- The teacher's role. While highly motivated pupils may learn concept and dialogue mapping from a brief, solitary exposure, we are interested in its development as an intellectual discipline with wide application in the curriculum. How should dialogue mapping be introduced to different ages? What are the key roles for staff/peer interventions? What kinds of activities provide orientations that lead to better or worse deliberations?
- Software design. While brief, small scale mapping can be done with pen and paper, software clearly adds new possibilities, e.g. in terms of the unlimited canvas, iterative revision, reusable structures, customisable language, embedded multimedia, storage and retrieval, and working over the internet. What do trials with pupils and staff tell us about the digital tools we are offering them?

We will see these themes emerging as we analyse the case studies, and will revisit them in turn in our discussion. In Section 2, we introduce the idea of using diagrammatic representations to support the acquisition of scientific reasoning skills in secondary schools. Section 3 motivates the use of Dialogue Mapping as an approach, based on the hypothesis that its success in non-educational contexts may be transferable to gifted teenage pupils in the science classroom. In order to ensure quality of scientific argumentation, we introduce an “evidenced based dialogue mapping” approach, which integrates dialogue mapping with Toulmin's model of a scientific argument. In Section 4, we present the methodology applied to this research, which comprises a set of learning activities for applying dialogue mapping to arguing and writing in science, data collected and criteria for analysing extracts. Through three case studies, we describe pupils' achievements and difficulties in constructing scientific arguments. Section 5 presents our findings and our future work.

2. Could argumentative maps be useful for secondary school?

Clearly, no simplistic statements can be made about the merits of different media, ontologies and notations, since they each exert their own influence, and interact strongly with factors such as the learner's domain expertise, fluency with the tools, familiarity with each other, and the way in which their activity is designed (Veerman, 2003). However, based on some chapters in this volume, appropriately designed and deployed mapping tools can aid learning: to make sense of internet information (Zeiliger), clarify reasoning (Rider & Thomason), develop conceptual understanding

(Novak & Canas; Mariott & Torres), foster critical thinking (Reed & Rowe), collaborative inquiry and affordances of different representations for learning (Suthers).

As a practitioner working on science education for gifted school pupils, O'Brien (2003, p.70) concludes that argument maps offer:

- a permanent record of thinking on a topic that contributes to a debate;
- clarity and rigour in thinking by improving the sharing of knowledge in a group leading to a deeper understanding of issues;
- efficient ways to present overviews indicating boundaries of current knowledge or debating in complex argumentation to another pupil;
- better decision making by ensuring that a higher proportion of relevant considerations are taken into account.

Specifically, in science education, there are studies using graphic representations to help students argue in science in high school and higher education. For instance, Schwarz and Glassner (2003) analysed argumentation as a central form of literacy with high school pupils in physics. Suthers (2003, chapter X) investigated scientific argumentation for collaborative inquiry with undergraduate pupils in physics. In the literature, several researchers have developed argumentation with younger pupils, but without computer support (i.e. Driver, Newton, and Osborne, 2000; Hogan and Maglienti, 2001; Jaubert and Rebiere, 2005; Manson and Boscolo, 2000; Means and Voss, 1996; Ratcliffe, 1997).

This is the first work to explore the potential of using a particular approach called Dialogue Mapping for young secondary school pupils to construct their scientific arguments. Children and teenagers frequently argue in home and at school, asking questions, giving answers and reasons for and against. They also have to give counter-arguments to refute other's opinions. The components of their argumentative conversation – questions, answers, pros, cons, comments and conclusions – are similar to those used to represent dialogue maps, as described next.

3. Adapting Dialogue Mapping for scientific arguing

Dialogue mapping is a knowledge mapping technique developed by Conklin (2006) to build shared understanding during discussions. Dialogue mapping extends the Issue-based Information System (IBIS) created by Rittel in the 1970s to solve ill-structured problems – denominated “wicked problems”. IBIS is a rhetorical grammar with three core elements, issues, positions and arguments, which can be rendered as textual outlines and as “graphical IBIS” (gIBIS) networks that grow with the conversation (Conklin and Begeman, 1988). Extended by Compendium visual hypermedia tool, this technique has been applied in organisations and companies by researchers, training facilitators, consultants and team leaders in support of collaborative sensemaking (Selvin, chapter X; Ohl, 2008; Sierhuis and Buckingham Shum, 2008). Given the success of Compendium in these sectors, and the growing need to begin instilling argumentation literacy at an early age (with a specific interest in science), the question arises: Could dialogue mapping be equally useful in the classroom, to help pupils argue scientifically?

In order to show how dialogue mapping can be used to represent the process of arguing, we selected this example below, which collates responses posted online at the summer school where pupils were asked: “what makes a good scientific argument?”.

Teacher: What do you think makes a good scientific argument?
 Kim: It must include questions, answers and explanations of the reason why.
 Sara: Statistics are very useful and gives readers an idea of amount or what you are talking about
 Beth: Evidence and strong pros and cons and a good topic to base the argument on
 John: A good scientific argument consists of a good question, a good strong fact with an even better argument!
 Peter: An argument showing both sides fairly with evidence for them and some biased comments for the side that you support but be careful you don't contradict yourself
 Alex: A logical, well thought out statement that works in putting your thought across in a few concise sentences
 Tina: Keep arguing and go over all evidence and always confirm it.
 However, nether be biased and expect to be surprised, not all discoveries are predictable.
 Lucy: The more facts the better

Extract 00 - Responses from Totally Wild Science Course in Moodle

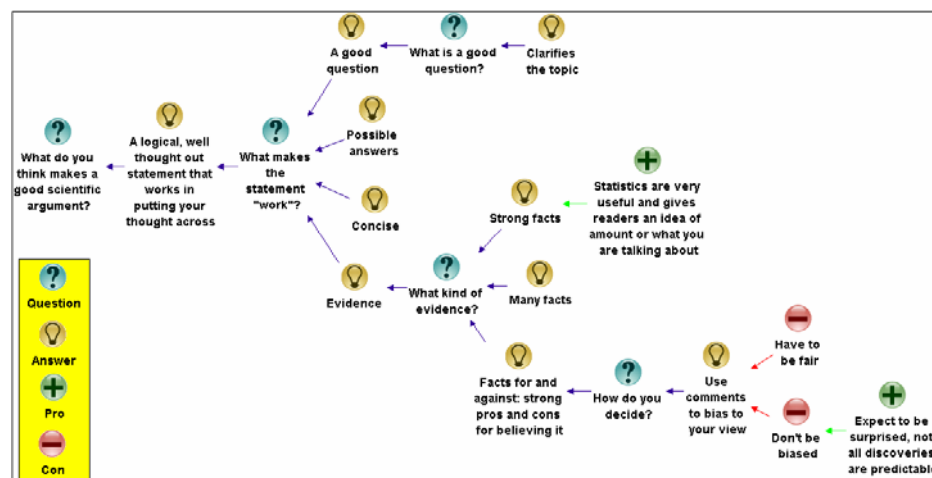


Figure 1. Dialogue map in Compendium (tool described in chapter X by Sierhuis and Buckingham Shum).

In these maps, the Compendium icons were used to represent questions (question node), answers (answer node), arguments (pro node), counterarguments (con node) and data (note node). As we can see, this map could have different representations, depending on the interpretation of the group and mapper. If the discussion in Extract 00 was Dialogue Mapped by a beginner, they might capture contributions more or less as they were uttered, and linked to reflect the temporal sequence. However, Dialogue Mapping at its best helps to clarify the key Issues, thus illuminating how the other contributions relate to these in the form of Ideas responding to those Issues, and the relative Pros and Cons of each Idea in that context (Figure 1). The emphasis thus shifts from chronological structure to logical structure. The challenge is how teacher intervention, software tools and practice can effect this shift in students, from naturalistic reasoning/discourse to conceptual reconstruction.

While IBIS provides a relatively intuitive language, as we discuss next, it is missing a key element central to scientific argumentation: evidence.

Evidenced-based Dialogue Maps

In scientific reasoning, it is important that the pupils can ground their claims in scientific concepts instead of personal convictions. The quality of their arguments is also better if they can connect not only supporting arguments, but also counterarguments (thus resisting confirmation bias), and data as backing for claims.

In order to represent the components of a scientific argument for teachers, Simon et al (2003) adopt the well known Toulmin (1958) model (shown in figure 2; also discussed in chapter X by Rowe and Reed; and Carr, 2003). In their research, the Toulmin approach was applied for teachers to guide pupils in structuring their argumentation scientifically and assessing the quality of their argumentation.

Toulmin's model can be re-expressed in dialogue mapping's IBIS language as shown in figure 3 (Carr, 2003). Following dialogue mapping's conversational paradigm, the link arrows go from right to left since they *respond to* or otherwise build on prior contributions, as shown by the various link types (*supports*, *challenges*, etc.).

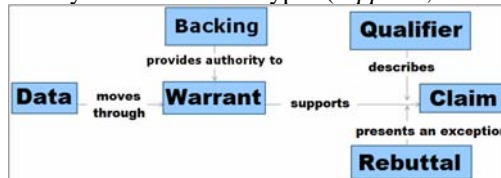


Figure 2: Toulmin argumentation scheme

In Toulmin form, there are six basic components of an argumentative move:

1. Claim: is the position on the issue and the essence of the argument. This represents the arguer's conclusion.

2. Data: i.e. initial grounds for the argument and evidence that can be accepted as factually true. This can be based on facts, events, examples and statistics.

3. Warrant: evidence used to support the connection between the data and the claim. It can be "authoritative" based on a reference by an expert; "motivational" based on convictions or "substantive" based on example, classification, generalization or cause and consequence. In science, the quality of the warrant is based on scientific concepts (substantive) rather than own convictions (motivational).

4. Rebuttal: This states the exceptions to the claim and is an exception to the truthfulness of the argument. It illustrates instances where the argument may not be true.

5. Qualifier: This states the "strength" of the claim. It represents the validity of an argument and indicates the context or circumstances where the argument is "true".

6. Backing: A source of authority for the warrant.

However, in this study we selected only four components of Toulmin's model - claim, warrant, rebuttal and data. These were considered by the science teacher to be the most relevant elements for pupils to incorporate into a scientific argument and a simple approach to scaffold their arguing skills.



Figure 3: Evidenced-based Dialogue Map

Figure 3 shows the scientific argument structure created in Compendium which we call as “evidenced-based dialogue map”. The connections between these components are not exactly as Toulmin’s model. It is a simple structure for scientific explanations, whose a claim should be connected to one or more warrants, rebuttals and data in order to demonstrated the evidence for the claim. Considering the vocabulary of these 12-13 years old pupils, these four components refer to answers, pros, cons and data (shown in extract00).

In this context, we examine whether Compendium helps pupils write scientific arguments. Our hypothesis is that it does so by scaffolding the task, breaking down the process into a series of more manageable and visualisable steps for pupils:

1. Represent initial reasoning in the form of a map, using Compendium’s icons to show the parts of the argument visually.
2. Use these visualised components to elicit further existing knowledge, and add this to the map.
3. Assess the strengths and weaknesses of the reasoning, by seeing if the claims are backed up with enough evidence.
4. Once the reasoning is strengthened, to transform the map into a linear text-based argument.

These four steps were used to plan the learning activities described in the following section.

4. Methodology: constructing scientific arguments in Compendium

Context: a science summer school

In this research, we observed 20 “gifted and talented” pupils who volunteered to attend a summer course “Totally Wild Science” during their school holiday in 2006. “Gifted and talented” is a term used in the United Kingdom for pupils who are in the top 10% of the national average based on their performance in formative assessment and test scores. The educational science consultant who organised this course with the educational committee of Canterbury Christ Church University selected 12 - 13 year-old teenagers, from different schools in the United Kingdom, based on an essay that described why they wanted to take this course and why they were very good at learning science.

“Totally Wild Science” was a science course organised around three topical themes: Forensic Science, Space, and Environment, with the aim of engaging pupils to develop their science learning skills. The main approach of this course was to use a great variety of learning projects in the science and computer laboratory, virtual learning environments and events such as trips and workshops with scientists. The main aspect of this course was to help them apply their own knowledge in projects in order to develop their scientific skills, rather than teaching new science concepts.

This research focused on the Environment project: “Global Warming – what do you think will happen in the future?” We developed a set of activities using dialogue maps about global warming with the science teacher. The tasks were published in the Moodle virtual learning environment, which was used to support collaborative learn-

ing. Pupils recorded their discussion and dialogue maps in a Moodle Forum (threaded discussion tool). They also posted their essays based on their dialogue maps. During this process, they described their progress and reflected on their difficulties and improvement. Compendium was introduced by the author, who demonstrated how the discussion between the science teacher and pupils could be recorded by dragging and dropping Compendium icons: questions, answers, pro, cons and notes. Some examples were presented to illustrate a dialogue mapping structure. The science teacher explained the importance of organising scientific arguments through these icons. Each answer should be connected to pros, cons and data. He showed some examples of maps based on figure 3.

Although pupils were using Moodle and Compendium for the first time, they did not encounter difficulties in manipulating these tools. Dragging and dropping information from the web and Moodle into Compendium (illustrated by figure8) was straightforward. This level of digital literacy enabled us to start the project with new tools with a brief introduction.



Figure4 A pupil working with Compendium (left), dragging data from web (right) into her map

Learning activities

In this *Global Warming* project we organised seven activities (Table 1).

Learning activity	Tools
“Reflecting on Writing in Science”: 1. How much do you like writing in science? (1= not at all, 3=OK, 5=I really like it) Give a reason. 2. What do you think makes a good scientific argument?	Moodle -ForumI.
“Writing about Global Warming”: Elaborate a composition in pairs about “What will be the impact of Global Warming (crops, diseases, ecosystem, water or weather)?”. Share it in the forum discussion.	Moodle -ForumII.
“Mapping Scientific Arguments”: Use Compendium for arguing about “What you think will happen in the future in the UK?” Represent your answers, arguments, “facts and evidence” .	Compendium, Moodle - ForumIII.
“Mapping data from the web”: Enrich the map with significant information from the internet and prepare a better argumentation structure.	Compendium, Internet, Moodle - ForumIV.
“Editing and improving map”: Improve scientific arguments in the map by using teacher’s feedback and focussing on the strongest idea.	Compendium.
“Writing from your map”. Export your map as an image or a list. Bring it into Word. Write your composition from this map and share your map and text	Compendium, Word, Moodle - ForumV.
“Reflecting on writing from maps”: Share your opinion about your learning, the use of Compendium and dialogue mapping applied to writing.	Moodle - Forum VI.

Table1. Learning activities - using dialogue mapping for arguing and writing about global warming

Data Focus for this study

The method of this qualitative research was case studies involving qualitative analysis. We collected discussions, maps, writing and notes posted by pupils and the teacher in Moodle, which served not only as a collaborative learning environment but also as a data archive for subsequent analysis. We also collected the teacher's private annotations during the project. The analysis consisted of three stages: (1) preliminary consideration of all recorded data (40 maps, 40 messages and 20 writings); (2) detailed examination of each pair of pupils who worked together analysing what they have produced (3 maps, 4 messages and 2 writings), (3) deep study of three cases which were selected because they were distinctive, as defined by tables 2 and 3.

Criteria for analysing the extracts

Based on the Toulmin argument scheme, we described 4 levels of argumentation and writing. These two tables were used as a reference to guide the case studies analysis.

Level of argumentation	Description
(1) no argument	Only claims
(2) weak	Claims and (weak) warrant (based on convictions)
(3) simple	Claims, (weak) warrants and rebuttals or data
(4) strong	Good Claims, good warrants, rebuttals / data

Table 2.. Criteria for analysing level of arguing

Level of writing	Description
Very Weak	Few words, no sentences, weak argumentation
Weak	Few sentences with weak or simple argumentation
OK	Connected sentences with simple argumentation.
Good	Well connected sentences with strong argumentation.
Very Good	Good paragraphs with strong argumentation and domain knowledge

Table3. Criteria for analysing level of writing

We present data from three pairs of pupils for range of sources, since they represented different outcomes. Like the rest of the class, these six teenagers did not enjoy writing in science. None of them had problems in using Compendium, although they encountered difficulties in dialogue mapping which we will describe.

Case A analysed data from pupils who had difficulties in writing and arguing. Their writing in science was considered “weak” by the science teacher; because they did not apply enough science concepts and their arguments were based on personal convictions. The level of argumentation dropped in their first map (from level 2 to level 1), then it gradually improved (from level 1 to level 3). Their final essay showed that mapping did not help them construct significant arguments. Although it contributed to making their writing clearer – level “ok”, their argumentation were not strong because they did not present enough data nor counterarguments. Here, we focus on analysing their difficulties.

Case B analysed data from pupils with poor skills for writing and arguing. Their first writing before mapping was classified as “very weak” with no arguments. In their maps, the level of argumentation gradually increased (from level 2 to level 4). At the end, their composition from maps was significantly improved -“good”. They included data and counterarguments, but they were not able to include science concepts to ground every claim. Here, we focus on analysing their achievements.

Case C analysed pupils who were good at arguing and writing, but presented initial difficulties in mapping. At the beginning of their project mapping was neither easy nor useful for them. Their level of argumentation dropped from 4 (in their writing) to 2 (in their first map). During the mapping activities, their scientific arguments were gradually improved (from level 2 to level 4). At the end, they were also able to present significant improvements in their writing, which was considered “very good”. Here we focus on mapping skills for constructing scientific arguments.

Table 4 summarises the level of argumentation and writing based on tables 2 and 3 during their learning activities. In forum2, they recorded their initial writing. In forum3, they created their first map. In forum4, they improved their map by bringing data from the web. In forum5, they prepared the final version of their map, exported to web outline and from a sequential list of components they elaborated their writing.

Case	Pupil	Forum2 1 st Writing	Forum2 Arguing	Forum3 1 st Map	Forum4 2 nd Map	Forum5 3 rd Map	Forum5 Final Writing	Would you use maps?
A	Alan	Weak	(2)	(1)	(2)	(3)	Ok	No
	Alex							Maybe
B	Beth	Very weak	(1)	(2)	(3)	(4)	Good	Probably not
	Ben							Yes
C	Chris	Good	(4)	(2)	(3)	(4)	Very Good	Yes
	Carl							Yes

Table 4. Level of argumentation and writing of 3 pairs of pupils

4.1 CASE A

In Extract A.1, two pupils who worked together explain why they don’t like writing in science. For Alan, writing is “*painful*” and for Alex, “*it helps for revision but is boring*”. Both were able to provide a reasonable answer to “*what makes a good scientific argument*”. They also constructed an argument about the future of the UK in the event of global warming.

Teacher: How much do you like writing in science? (1= not at all, 3=OK, 5=I really like it).
 Alan: Not at all. Because I get cramp in my wrist easily, so it is actually painful to write large amounts by hand.
 Alex: OK. It helps for revision but gets a bit boring. It is more fact than fiction. It is more remembering than imagining.
 Teacher: What do you think makes a good scientific argument?
 Alan: A good scientific argument consists of a good question with a good strong fact with an even better argument!
 Alex: A theory and logical, well thought out statement that works in putting your thought across in a few concise sentences.

Extract A.1 from the Forum I – “Reflecting on writing in science”

Extract A.2 shows these pupils’ writing. Their answer was based on a long sentence, which presented their ideas, argument and a short science explanation.

Teacher: Write down for your topic: What you think will happen in the future in the UK?
 Re: Writing about Global Warming - Group Water by Alan and Alex.
 If the ice caps do melt and the product of the melting (the water) goes into the sea (which it will) it will make the water levels rise dramatically and flood villages, towns, cities and maybe even small countries! Shocking(!) The reasons for these ideas are really just logic.
 Teacher: Why will water levels rise dramatically if the ice caps melt?

Extract A.2 from the Forum II – Writing about Global Warming

In order to analyse the level of argumentation of these pupils' writing, the author created the map below (figure 5) in Compendium. By interpreting their answers graphically based on Toulmins' model, we can see that they included a claim, a warrant and one piece of data. The level of this argumentation is 2. They were able to connect warrant and a concept to support their claim, but they were not able to apply knowledge scientifically. They presented strong conviction ("*which it will*") to support their answer, but they did not provide enough justification. The argument is sound in structure. However, they were not able to explain how ice caps melt would make the water levels rise "*dramatically*". They did not include data showing the risk of flooding in the UK nor any rebuttals.

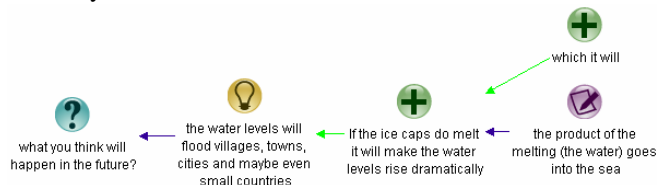


Figure 5 – Map created in Compendium based on Toulmin's models

Extract A3 shows the first dialogue map this pair created in Compendium. They generated eight questions and six short answers. Although their questions were very relevant and imaginative, their answers were very short ("*yes*", "*no*", "*probably not*") and there were no arguments.

Re: Mapping scientific argument - Group Water by Alan and Alex



Teacher: What are your main questions? What pros and cons can you include?

Extract A.3 from the Forum III – Mapping Scientific Arguments

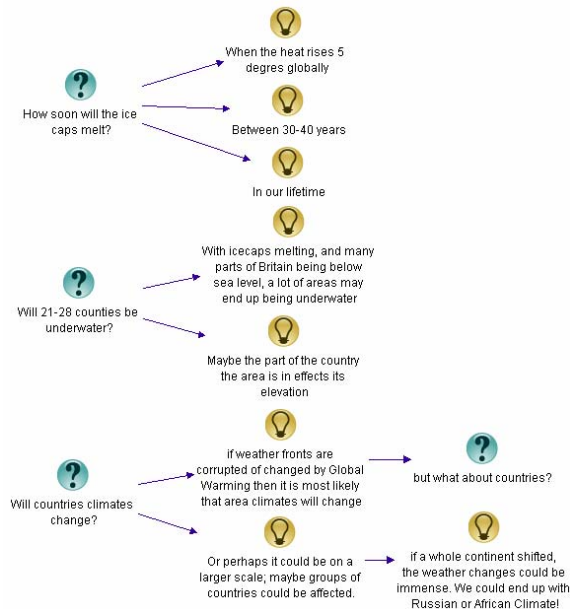
For these pupils, writing an argument in the discussion forum was quick, but representing an argument graphically was very hard. They spent a long time, and they were not able to structure clearly their reasoning. Reading the content of this mapping is a

little distracting, and it is easy to be lost. In this intricate structure, connecting pros, cons and data for each answer is more difficult because the information is not well organised spatially. The level of their argumentation in this map is 1 – weak claims (e.g. “yes”, “*in our lifetime*”, “*between 30-40 years*”,...) and no arguments (neither pros nor cons). Comparing the argumentation in their writing (Extract A.2) to their first map, the quality dropped from level 2 to level 1. Looking at their short answers, it is hard to identify “*well thought out statements*”, because they are incomplete sentences. These few words only make sense if we read the questions, but each answer addressed several questions.

In this case, Compendium functioned as a brainstorming medium which helped them to generate several interesting questions about implications for policy and action. They were able to go through a rich process of questioning. As Alex mentioned “*a good scientific argument consists of a good question*”. However they were not able to connect warrants, rebuttals and data in their map. In this case, the challenge for teachers is to help pupils find ways to reorganise their map. Pupils who are not good visual thinkers and not familiar with mapping techniques will need more support for establishing good connections between components.

Extract A.4 shows their map after teachers support. The pupils improved the structure and they were able to construct scientific claims through full sentences. This new structure suggests a sign of substantial cognitive change. This process is not quick; they spent a long time restructuring their map. In this activity, ‘Mapping data from the web’, they did not access the internet because they were focussed on disentangling their ‘intricate web’ and clarifying their thinking. They deleted many nodes; some of them were excluded accidentally (as described in extract A.6).

Re: Mapping scientific argument - Group Water by Alan and Alex



Teacher: What are your main ideas? Could you include pros, cons and data?

Extract A.4 from the Forum IV – “Mapping data from the web”

Extract A.5 presents their final map and composition. In the map, we can notice their difficulties again in organising the structure of nodes, in choosing icons and making connections. The arrows, again, were represented in different directions.

```

graph TD
    Q1[?] --> A1[With icecaps melting, and many parts of Britain being below sea level, a lot of areas may end up being underwater.]
    A1 --> Q2[?]
    Q2 --> A2[Maybe the part of the country the area is in affects its elevation.]
    A2 --> Q3[?]
    Q3 --> A3[If weather fronts are corrupted or changed by Global Warming then it is most likely that area climates will change.]
    A3 --> Q4[?]
    Q4 --> A4[but what about whole countries?]
    A4 --> Q5[?]
    Q5 --> A5[Or perhaps it could be on a larger scale, maybe groups of countries could be affected.]
    A5 --> Q6[?]
    Q6 --> A6[If a whole continent shifted, the weather changes could be immense. We could end up with Russian or African Climate!]
    A6 --> Q7[?]
    Q7 --> A7[The percentage of Earth's land area stricken by serious drought more than doubled from the 1970s to the early 2000s.]
    A7 --> Q8[?]
    Q8 --> A8[Will the increasing amount of water affect the Continental Plates?]
    A8 --> Q9[?]
    Q9 --> A9[Then again, the water being added to the ocean is either neutral or possibly alkaline, so surely it wouldn't have an effect on the ocean floor or the Continental plates.]
    A9 --> Q10[?]
    Q10 --> A10[The Earth's crust heats up to keep up with the external climate, this may disrupt the plates.]
  
```

will 21 - 28 counties be underwater?

With icecaps melting, and many parts of Britain being below sea level, a lot of areas may end up being underwater.

Maybe the part of the country the area is in affects its elevation.

If weather fronts are corrupted or changed by Global Warming then it is most likely that area climates will change

but what about whole countries?

Will countries climates change?

Or perhaps it could be on a larger scale, maybe groups of countries could be affected.

If a whole continent shifted, the weather changes could be immense. We could end up with Russian or African Climate!

The percentage of Earth's land area stricken by serious drought more than doubled from the 1970s to the early 2000s

Will the increasing amount of water affect the Continental Plates?

Then again, the water being added to the ocean is either neutral or possibly alkaline, so surely it wouldn't have an effect on the ocean floor or the Continental plates.

The Earths crust heats up to keep up with the external climate, this may disrupt the plates.

“Will 21-28 counties be underwater? With icecaps melting, and many parts of Britain being below sea level, a lot of areas may end up being underwater. Maybe the part of the country the area is in affects its elevation.

Will countries climates change? If weather fronts are corrupted or changed by Global Warming then it is most likely that area climates will change. It could be on a larger scale. Maybe groups of countries could be affected. If a whole continent shifted, the weather changes could be immense. We could end up with Russian or African Climate! The percentage of Earth's land area stricken by serious drought more than doubled from the 1970s to the early 2000s.

Will the increasing amount of water affect the Continental Plates? Then again, the water being added to the ocean is either neutral or possibly alkaline, so surely it wouldn't have an effect on the ocean floor or the Continental plates. The Earths crust heats up to keep up with the external climate, this may disrupt the plates.

Extract A.5 from the Forum V – Writing from your map

In their second paragraph, they came up with a series of plausible claims, but rarely included relevant data, and did not establish a relationship between the claim (e.g. *“If a whole continent shifted, the weather changes could be immense”*) and the evidence (e.g. *“The percentage of Earth's land area stricken by serious drought more than doubled from the 1970s to the early 2000s”*). In their third paragraph, the argument is good, but the science knowledge (suggesting that climate change might alter the structure of the Earth's tectonic plates) does not make sense. Their argumentation did not improve significantly comparing the initial writing (level 2) with their final composition (level 3). There are more sentences organised in better sequences, they could visualise their strongest ideas, but they did not develop the quality of arguments, they were not able to identify where they should connect more evidence. They did not add strong warrants, rebuttals and enough data. There were no strong connections based on science concepts between their claims.

Extract A.6 shows pupils confirming that mapping was not significant to construct arguments. *“The map doesn't make things any easier”*. *“A written explanation can be clearer”* than a graphical representation of argumentation. For these pupils, *“it is easier to just think through an argument than make one on compendium”*. About mapping for writing, Alan states *“The map doesn't make things any easier”*. For Alex mapping *“makes writing quick and efficient, but some good detail can be lost.”*

Teacher: How useful do you think maps are for constructing scientific arguments? Give reasons.

Alan: Little use. For me it is easier to just think through an argument than make one on Compendium.

Alex: Good, but a written explanation can be clearer

Teacher: Did you find any problems during the process of mapping?

Alan: It was a little bit fiddly, and I accidentally deleted things a few times.

Alex: Not really

Teacher: Would you use a map in future? If so, say why?

Alan: No. Alex: Maybe, it depends on what it would be used for

Teacher: Overall, does the map make the process of writing any easier? Why?

Alan: The map doesn't make things any easier.

Alex: It briefs things. that makes it quick and efficient but some good detail can be lost

Extract A.6 from the Forum VI – Reflecting on writing from maps

In summary, the pupils turned dialogue mapping into a ‘brainstorm of questions’. Constructively, the pupils generated several new interesting issues, but their argumentation remained poor. A good question is often a good starting point for creating a scientific argument: incisive issues can presumably only help scientific inquiry. However, in the process of brainstorming in the ‘blank canvas’ of Compendium – one of pupils’ difficulties was to organise icons and arrows on the screen. A strong visual template could probably help them develop their scientific arguments.

Selvin (chapter x) points out that practitioners (Compendium users) need important skills for constructing good dialogue maps. Rider and Thomason (chapter x) show the importance of developing lots of argument maps to create good argumentation. Pupils need to learn how to structure all issues properly in the map to avoid a confusing layout. If pupils create an intricate web of ideas, than teachers need to help them disentangle it, because the more complex is the format of their map, the more difficult will be editing and improving it. It is important to teach how to establish good sequences and connections between components. At the same time it is good to have

initially the flexibility to allow pupils shape their reasoning by creating nodes and connections without feeling attached to a particularly structure.

4.2 CASE B

Case B shows quite structured mapping, which helped pupils generate evidence-based claims. Their maps provided visual guidance for them to identify for which claims they could develop arguments using their existing knowledge, and which they could not.

Extract B.1 presents this pair of pupils who dislike writing in science as well. Beth “*hardly ever does it and always gets stuck for an answer*”. For Ben “*doing it fully and properly is V. Tedious and Tiresome*”. They were able to describe what makes a good scientific argument. However, they had serious difficulty in writing an argument.

Teacher: How much do you like writing in science? (1= not at all, 3=OK, 5=I really like it).
 Beth: 2. Because I hardly ever do it and I always get stuck for an answer
 Ben: 3. Writing is ok for me. I don't mind writing and sometimes it can be good, but doing it fully and properly is V. Tedious and Tiresome
 Teacher: What you think makes a good scientific argument?
 Beth: Evidence and strong pros and cons and a good topic to base the argument on.
 Ben: I think that good sturdy evidence is obviously the basis to a strong conclusion and also to try and disprove any other theories by any means possible

Extract B.1 from the Forum I – “Reflecting on writing in science”,

In extract B.2, we can see their text posted in the forum. Their writing was based on short answers of a few words, with no sentences, and critically, no arguments. They did not give reasons for their answer and they were not able to justify their ideas using “*evidence*” or “*pros and cons*”.

Teacher: Write down for your topic: What you think will happen in the future in the UK?
 Re: Writing about Global Warming - Group Ecosystem by Beth and Ben
 Impacts on nature. Disappearance of many wetlands and extinction of some species.

Extract B.2 from the Forum II – Writing about Global Warming

Figure 6 shows a map created by the author to represent the level of argumentation of these pupils’ writing. Based on Toulmin’s model, we can see that all components are claims. They did not present any warrant, data or rebuttals. Their level of arguing and writing is very weak (level 1).

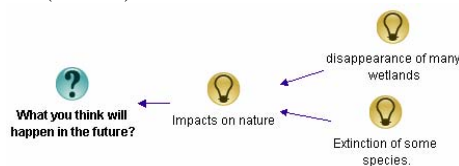
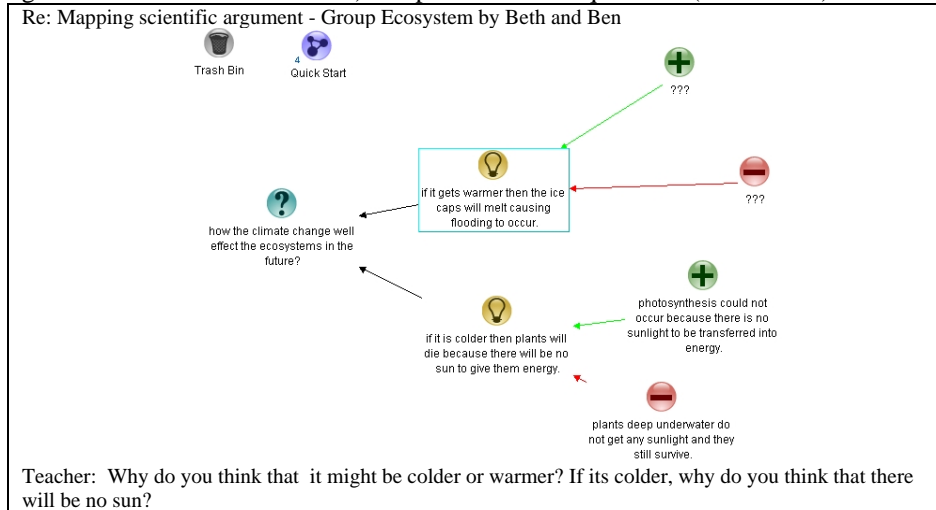


Figure 6 – Map created in Compendium based on Toulmin’s models

Extract B3 shows their first dialogue map in Compendium. They generated a question, two answers, a pro and a con. Interestingly, for each answer, they represented a clear intention of supporting and challenging it by bringing pros and cons. For the second idea, they were able to bring an argument and a counterargument. However, they were not able to explain their claims properly or connect data to them. Looking at their map, it was possible for the teacher to see immediately from the ‘placeholder’ Pro and Con nodes with question marks where they lacked information, and what role they saw this playing in their analysis (that is, how information fragments could be-

come contextualised knowledge). By looking at the text of each node, the science teacher could also identify problematic assumptions in their argumentation (e.g. if it gets colder there will be no sun) and pose follow-on questions (Extract B.3).



Extract B.3 from the Forum III – Mapping Scientific Arguments

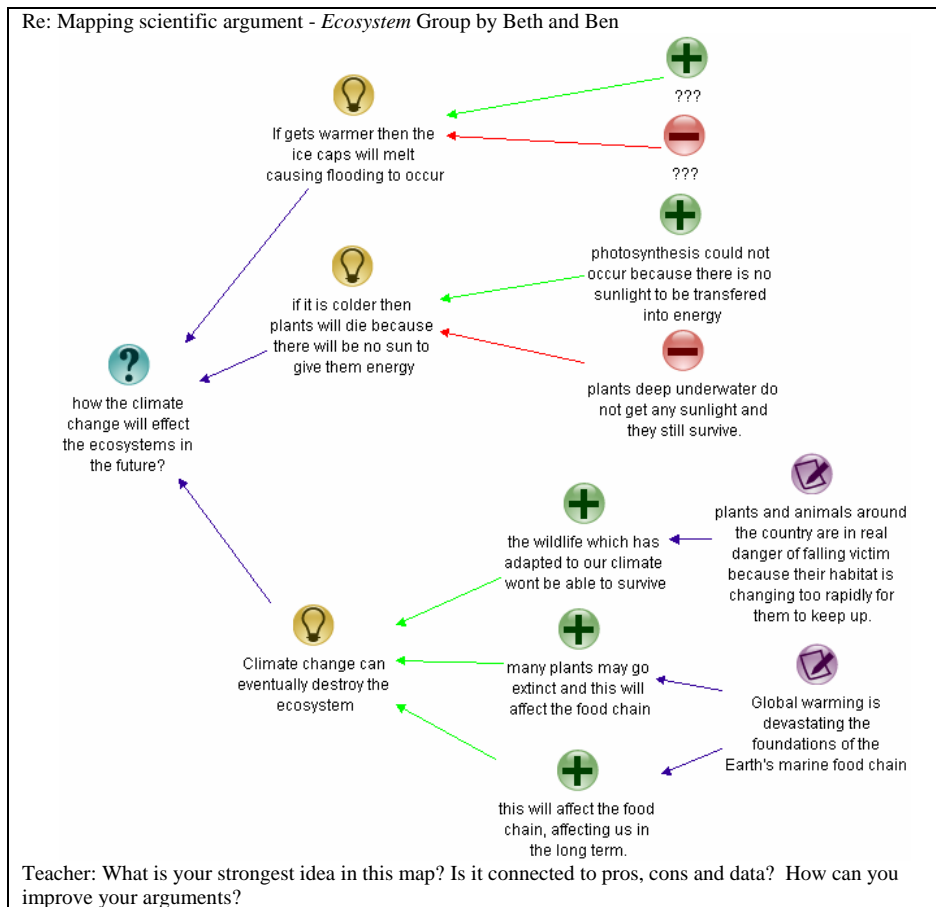
In order to analyse the level of argumentation embedded in their dialogue map, we examined each component directly from their Compendium map. They represented two claims using proper sentences but they were not able to establish good connections. Their level of argumentation in their first map (2) is better in the map than in their writing (1) because they included warrant and rebuttals, but it was not significantly improved. Looking at their second claim they applied successfully the concept of photosynthesis in order to justify that “*plants will die*” since “*there is no sunlight*”. However, this warrant was not substantive. They did not explain the connections between “*climate change*”, “*it might be colder*” and “*there will be no sun*”. This association was based on their own convictions. Their map suggests that they do not have clear understanding about the relationship between Global Warming and the Gulf Stream.

In this case, we would argue that while the visual IBIS language in dialogue mapping prompted them to bring warrant and rebuttals to ground each of their ideas, the nature of the argumentation did not show improvement, particularly due to the lack of science concepts presented in their map. They were not able to apply enough science concepts to support their main claims. The macrostructure of their reasoning was good (i.e. at the level of good IBIS form), but the microstructure was weak.

Extract B.4 shows their maps extended with data from two websites during the activity to map data from the web. Pupils brought two notes from the internet. Mapping the web was neither easy nor fast. For them, bringing data into the map did not mean simply dragging and dropping sentences into Compendium. They had to think about what to select and where to connect it. It is easy to visualise in the map where “*they got stuck for an answer*”. Although they could not answer the teacher’s ques-

tions (Extract B.3) to improve their two initial ideas, they selected two new pieces of information that helped them elaborate three arguments around a new answer.

Considering their new claim “*climate change can eventually destroy the ecosystem*”, their argumentation improved (from level 2 to level 3). They presented substantive warrants based on data (“*plants and animals...are in real danger*”, “*global warming is devastating...*”). However, their argumentation falls short of the ideal through the lack of any rebuttals.

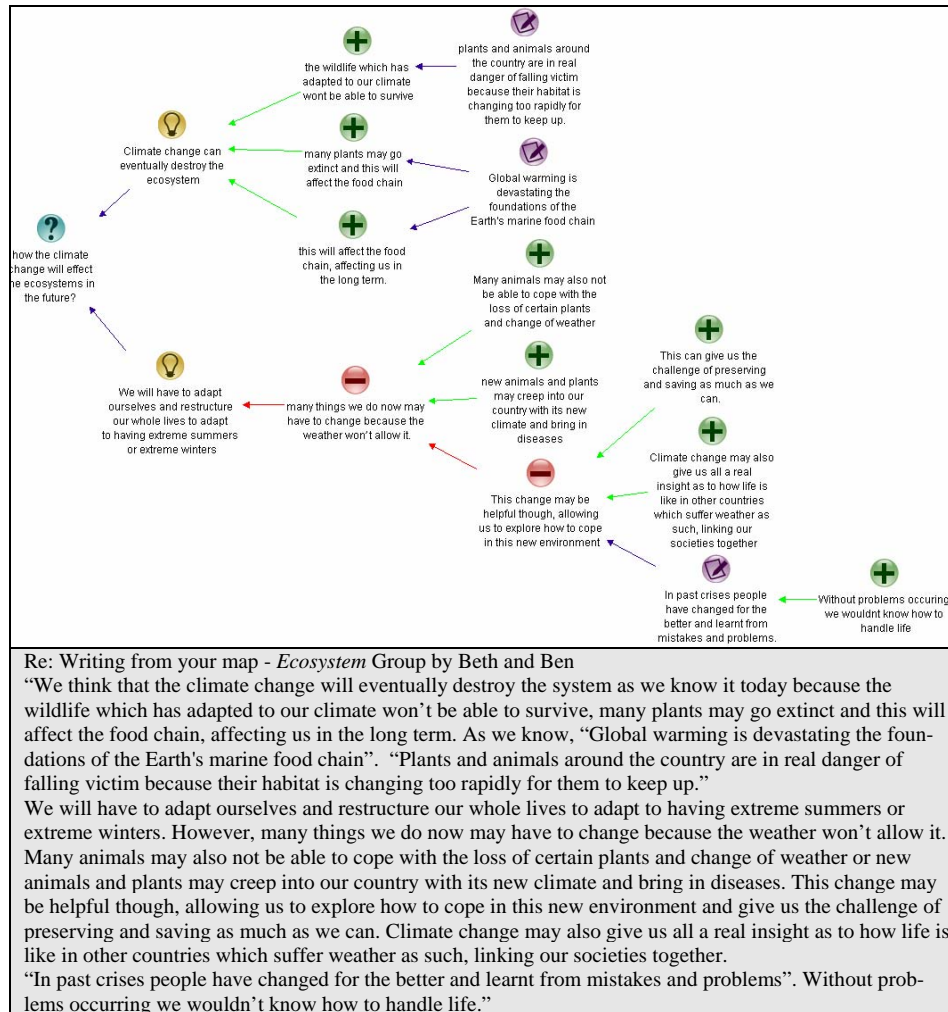


Extract B.4 from the Forum IV – “Mapping data from the web”

Extract B.5 shows their map edited after comments from teacher. From this map they elaborated their writing. Comparing this map with their previous one, their main change was focussing on their strongest answer by bringing more arguments, counter-arguments and notes. The part of the map that they “*got stuck for an answer*” they decided to delete.

As we can see, there was a significant improvement of the level of argumentation in their map (level 1 at the beginning and level 4 at the end) and in their writing (from “very weak” to “good”). They were able to bring more science concepts and also include other perspectives such as social and ethical issues. The science teacher con-

sidered the first paragraph good, but the second one could be better if they had added more science concepts rather than personal opinion.



Extract B.5 from the Forum V – Writing from your map

Figure 7 shows how Compendium was useful for pupils to structure their writing from their map. They exported it using the Web Outline View option which linearises the map into an indented list of nodes. They then edited the outline into more flowing prose.

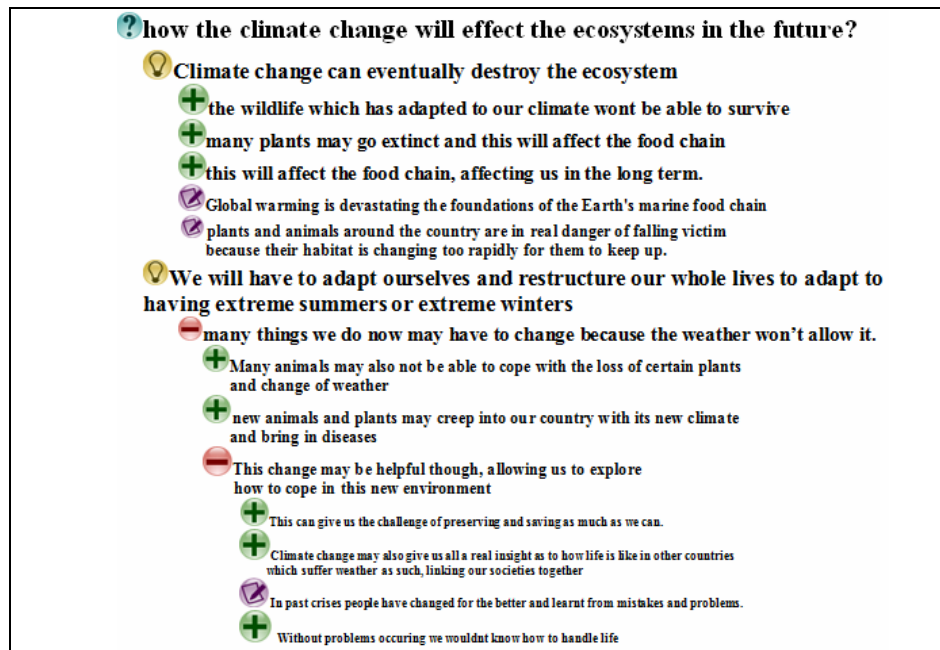


Figure 7 – List of topics generated by Compendium as a “web outline”

Extract B.6 shows how the pupils viewed this process. They had different opinions about how useful these maps were for constructing scientific argument. Ben found them “very useful” and “would use this type of map again”. Beth considered “useful” but “probably wouldn’t (use it again) because it took a bit too much time”.

Both of them described how maps helped them in several ways: “prove up their point”, “think of many ideas”, “construct a good fair balanced scientific argument” and “link arguments together with words for their composition”.

They did not have difficulties using Compendium, they considered “fairly easy”, “it was fine”. The “few problems” was “along the way like whether the nodes were right”. The tool was easy, but the mapping was hard!

Teacher: How useful do you think maps are for constructing scientific arguments?
 Beth: OK. They help prove up your point in an scientific argument. However, it takes a LONG time.
 Ben: They are very good because they help you to think of many ideas connect them and not miss anything out then you can construct a good fair BALANCED scientific argument (s.p) by using all of the nodes you have created and linking them all together with words.
 Teacher: Did you find any problems during the process of mapping?
 Beth: I encountered a few problems like whether the nodes were right, but other than that it was fine.
 Ben: No it was fairly easy
 Teacher: Would you use a map in future? If so, say why?
 Beth: I probably wouldn't because it took a bit too much time.
 Ben: I think i would because it is an easy way to sum up ideas for a report.
 Teacher: Overall, does the map make the process of writing any easier? Why?
 Beth: It does. Everything is there easy to read, not in your head where it may slip away.
 Ben: I think it does because it has all the information you need in the shortest formation possible. It is kind of like a sophisticated mind map. I AM DEAD.

Extract B.6 from the Forum VI – Reflecting on writing from maps

In summary, for these pupils, the process of thinking about the nodes is not trivial, nor quick. It takes a “*LONG time*” and one pupil declares at the end “*I am dead*”. As Conklin (2006) states there is lots of interpretation involved in dialogue mapping. In Compendium, for each node that they dragged and dropped into the screen, they had to tackle several implicit questions, such as “Is this icon right?”, “Is this text right?”, “Is this connection right?” (see Buckingham Shum et al, 1997 for detailed analysis of these cognitive tasks). If the pupils can be engaged in this process of thinking, and of course supported by their colleagues and particularly by the teacher, then this analysis illustrates how dialogue mapping can serve as a new kind of scaffold for improving scientific argumentation. Debating their map with colleagues and teachers requires them to address other relevant questions such as “Is this a strong idea?”, “Is this idea supported by robust evidence?” “Is this idea connected to pros, cons and data?”, “Are these arguments and counterarguments based on science concepts or on personal convictions?”, “What is the source of this data?”, Is this a reliable source?” If pupils can be engaged in all these kinds of questions, then thinking about “the nodes”, means thinking about the components of a scientific argumentation. Questioning “whether the nodes are right”, means questioning if their scientific reasoning is right.

Dialogue mapping, from the perspective of these pupils, functions as a “*sophisticated*” strategy for argumentation. By visualising “*all the information they need in the shortest form possible*” they were able to use the most significant components to construct “*a good fair BALANCED scientific argument*”. Dialogue mapping can also be an “*easy way to sum up ideas for a report.*”

3.3 CASE C

Case C presents another role for dialogue maps, “self assessment”. Once pupils are able to visualise their arguments through the right icons, they can recognise easily what part should be clarified, deleted or extended. The good use of icons helps them “make their points clearer and easier to understand” and also make it “easier for teacher to mark their ideas”. This kind of “formative assessment” – feeding back information to the learner about their understanding – is widely recognised as a major factor in enhancing achievement.

In Extract C.1, this pair of pupils explained that writing is neither as fun as practical nor as easy as presentations. For Chris “It is boring”. For Carl “writing is ok”, but “presentations to people you know are easier”. They wrote fluently, addressing the topic set by the teacher’s question, and giving good explanations of what makes a good scientific argument.

<p>Teacher: How much do you like writing in science? (1= not at all, 3=OK, 5=I really like it). Give a reason</p> <p>Chris: 3. Because you can get what you want to say across quite easily, but presentations to people you know are easier</p> <p>Carl: 2. It is boring, I have more fun in practical.</p> <p>Teacher: What you think makes a good scientific argument?</p> <p>Chris: EVIDENCE!! you need evidence to back up your ideas and arguments otherwise you don't have a very good case. Finally you need to be able to argue both sides of a case</p> <p>Carl: A good scientific argument puts across what you mean simply and clearly, keeps attention and is not too complicated, but does not leave out important logic steps (it shows your thinking well).</p>

Extract C.1 from the Forum I – “Reflecting on writing in science”,

Extract C.2 shows their writing with a good science argument. Their text was based on two short paragraphs, in few well-connected sentences. This text not only presents a good claim grounded in pros, cons and data, but also they were able to bring some science concepts to ground their answer.

<p>Teacher: Write down for your topic: (1) What you think will happen in the future in the UK? (2) give reasons for your idea</p> <p>Re: Writing about Global Warming - Group Diseases by Chris and Carl</p> <p>Global warming will either make Britain (focusing here for now) a lot warmer, or shut down the gulf stream and make it a lot cooler. Either way, we will face a rise in disease as cold weakens the immune system and heat causes dehydration, heatstroke and other health problems. Of course, if you take into account the cause of global warming, pollution, you have even more problems. Pollution causes eye and lung diseases.</p>

Extract C.2 from the Forum II – Writing about Global Warming

Figure 8 shows a map created by the author to represent the level of argumentation embedded in the pupils' writing. Based on Toulmin's model, we can see that they included the main components to ground their claim: claim, rebuttal, pros and "evidence to back up their ideas". The level of their argumentation and writing are very good.

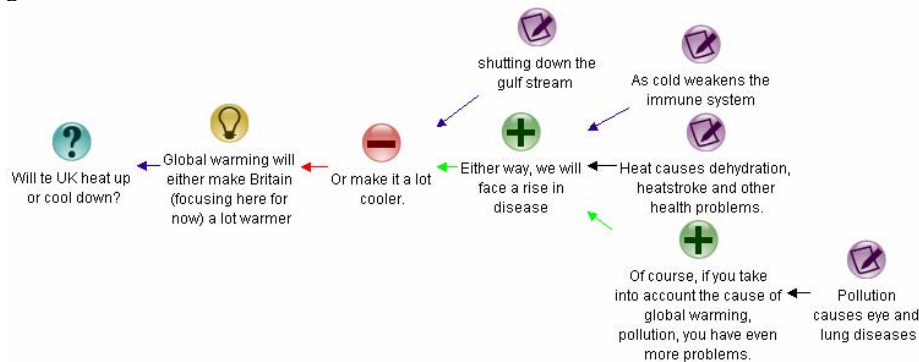
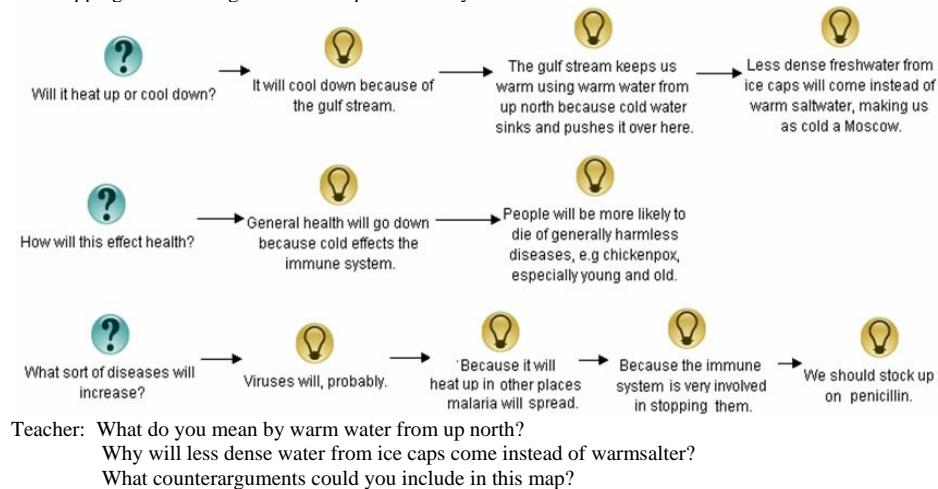


Figure 8 – Map created in Compendium based on Toulmin's model

Extract C.3 shows their first dialogue map in Compendium. They generated more questions and more claims. They extracted the different issues from their initial statements, and opened up discussion about them. They also described some science concepts giving more details. However, their arguments in the map were not as clear as in their writing (where they considered pros and cons and data for their main claim.) If they had included all these components of science argument, then the maps would be better. As they had difficulty in choosing the icons, they can not visualise what part could be improved. They represented all of them as answers in three linear sequences as if they were writing, which suggests that, in fact, they could have written these arguments without creating the map.

In this map, pupils were able to present warrants based on their science knowledge. However, the science teacher noticed they did not show a clear understanding about why the UK might cool down. Moreover, they did not include any counterargument. They had also difficulties in representing data through proper icons. The level of argumentation dropped from level 4 to level 2.

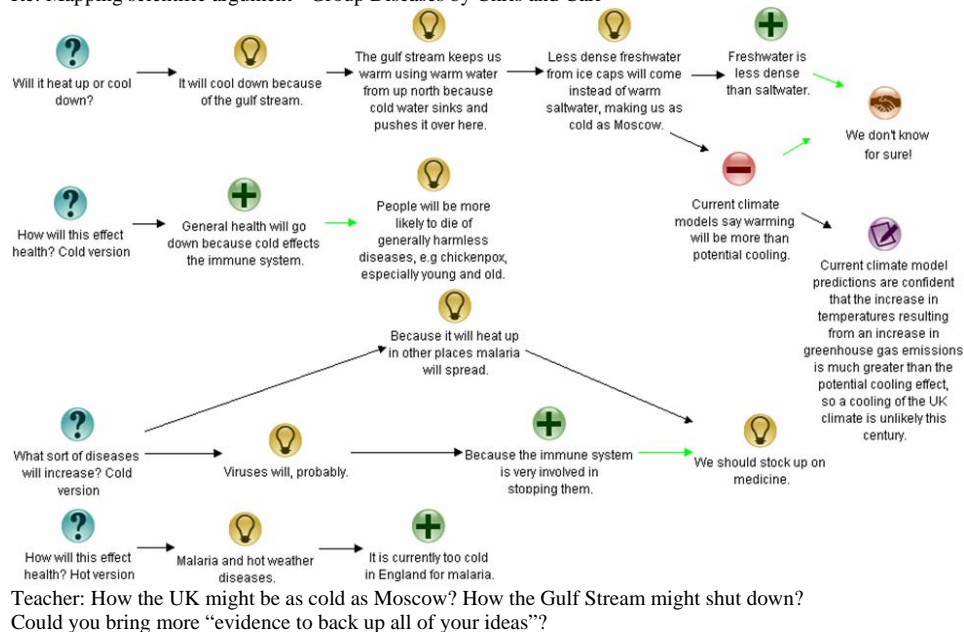
Re: Mapping scientific argument - Group Diseases by Chris and Carl



Extract C.3 from the Forum III – Mapping Scientific Arguments

Extract C.4 represents their map with information from the web. They added more data, questions and arguments. They also represented the components through different icons and established more connections between them. However they still were not able to explain clearly the effect of Global Warming and the Gulf Stream. They were also not sure about the difference between answers and pros.

Re: Mapping scientific argument - Group Diseases by Chris and Carl

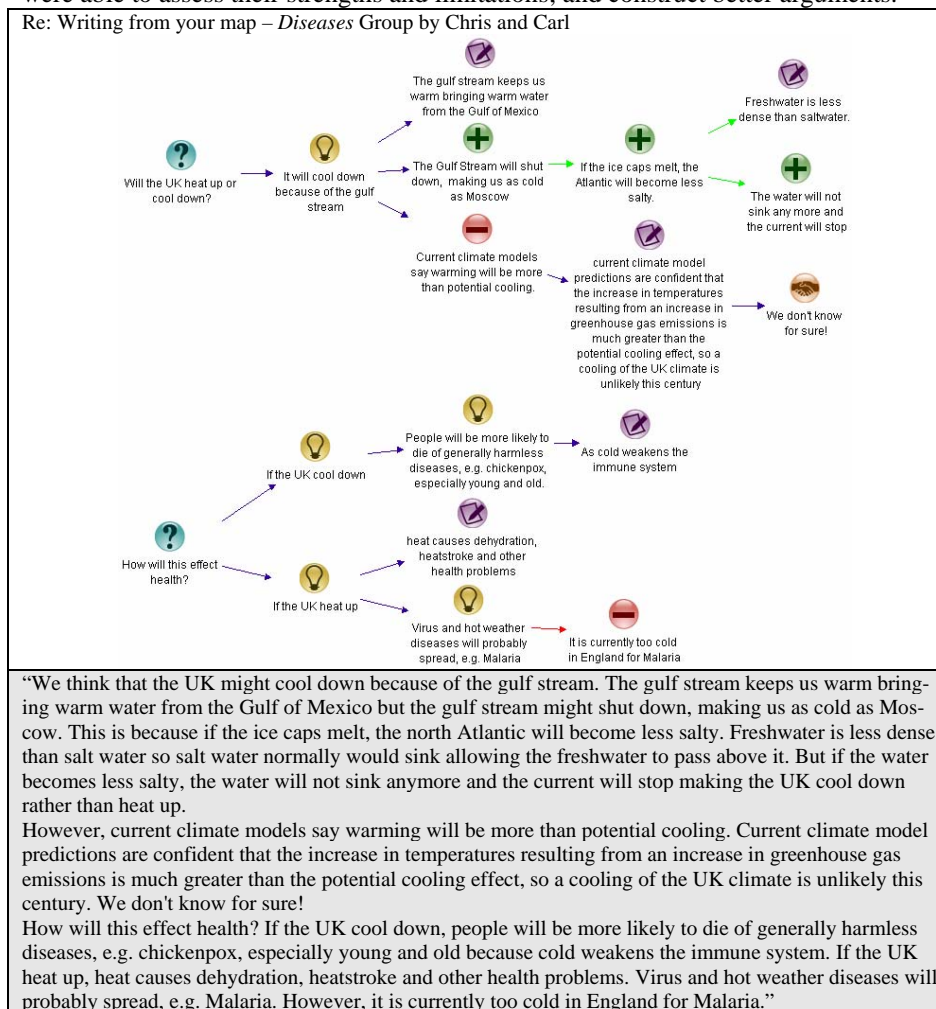


Extract C.4 from the Forum IV – "Mapping data from the web"

The level of argumentation in their mapping improved. However, it is not possible to conclude that mapping helped them to construct better arguments. They established good connections, not as linear as the previous map. However, their arguments in this map were not as well integrated as in their writing (figure 10) where we could see all of their arguments connected to data. In the writing extract C.2, as they mentioned, they were “focussed” on the main idea (“Britain, a lot warmer”) and they brought more components to ground that claim (figure 7). In the map in extract C.4, they raised more questions and open more statements, but they weren’t able to put their arguments together in order to construct a good argumentation.

Extract C.5 presents their final map and writing. After the teacher’s feedback and explanation about the Compendium icons, pupils were able to improve their map significantly. With better understanding to visualise the components of their map, they were able to assess their strengths and limitations; and construct better arguments.

Re: Writing from your map – Diseases Group by Chris and Carl



Extract C.5 from the Forum V – Writing from your map

They used the icons more systematically to express the roles played by each node:

- “note” to represent facts, concepts and data. These are their evidence, which means statements that can be considered acceptable as truth based on science. Normally they are presented with present tense verbs.
- “answer” to indicate their main claims which address their questions. As their questions refer to the future, these sentences are in the simple future tense.
- “pro” to show their arguments. This can also be in the future, but their function is to support or explain their main answer.
- “con” to introduce exceptions, opposite ideas, statements against.

Once they were able to use the icons properly, they really improved their map with better and more consistent explanation of the Gulf Stream. They also had a clearer visualisation about what their main viewpoint was, in order to support and challenge it. At the beginning they said that their focus was on “it will be warmer”, then after better explanation, they changed to “it might be colder”.

As they were able to construct strong argumentation on their map, and clear structure, it was easier for them to edit all the nodes from the map into a good composition. As they could clarify their understanding about the Gulf Stream, they could present better explanation in the composition which made it better than the previous writing. They were also able to visualise better what was their main proposition and describe it clearer on the text.

Extract C.6 shows how these pupils reflected as mapping for writing. Both of them considered it useful. They presented several reasons: “helped me to sort out my ideas and arguments”, “make my points clearer and easier to understand”, “It also helps you to think through the facts and how they affect your arguments.”

Although they considered it difficult to export and import maps in Moodle, they really showed interest in using mapping again. They also presented interesting reasons: “Writing from mapping “is more fun”, “Argument is more logical and ordered”, “It makes the whole thing a lot quicker”. They could also identify significant benefits such as “it would also be easier for a teacher to mark my ideas”.

Teacher: How useful do you think maps are for constructing scientific arguments?
 Chris: 4 It's reasonably good because it helped me to sort out my ideas and arguments and make my points clearer and easier to understand. I presume it would also be easier for a teacher to mark my ideas.
 Carl: 5. It was a really good tool to sort out your ideas with and was very effective. It also helps you to think through the facts and how they affect your arguments.
 Teacher: Did you find any problems during the process of mapping?
 Chris: The only problem I found was that the process of saving the maps, opening, exporting etc. was very complicated and I would not be able to do it by memory, I would need the whole process written down for me to do it by
 Carl: Importing and exporting were quite tricky and it would be easier if you could just save and copy and paste the text.
 Teacher: Would you use a map in future? If so, say why?
 Chris: I might use the map in the future because it makes writing easier for me to do personally and for other people to understand. Overall it makes life a lot easier for everyone and it is definitely a very useful
 Carl: Of course, but I wish saving the work was easier.
 Teacher: Overall, does the map make the process of writing any easier? Why?
 Chris: You can get down the basic ideas and link them together, making connections and then edit the same text, which makes the whole thing a lot quicker because you can actually use the notes you make.
 Carl: yes its more fun. I find when it comes to writing up an essay that my argument is more logical and ordered.

Extract C.6 from the Forum VI – Reflecting on writing from maps

In summary, we observed in case C that when pupils present good knowledge and arguments in their initial writing, maps can act as a tool for seeing whether they were able to apply their knowledge and formatively assessing their understanding. As pupils need to support their position in the map through connections, maps can reveal possible misunderstandings that their writing can not. Once pupils, through teachers' feedback, are able to clarify their connections, then they can enrich their argumentation and improve significantly their writing. Then, maps work as a tool for "sorting out their ideas and arguments". Their "arguments are more logical and ordered" and their "points are clearer and easier to understand".

5. Discussion: returning to our research questions

Encouraged by the success of Compendium-enabled dialogue mapping in non-educational contexts, we have presented the first step in our efforts to investigate its potential as a cognitive discipline, within a structured digital medium, to foster school pupils' scientific argumentation. We now discuss the preliminary answers that we can give to our opening research questions, based on the analyses of pupil pairs A-C.

Scientific knowledge and mapping

In our case study pairs, we saw examples of superficially well-structured maps with poor argumentation, and of poorly structured maps with good argumentation embedded in the labels of nodes. We saw how the visual language of IBIS can provide a template, for instance, cueing pupils that at least one Pro and Con are expected to be linked to each Position, even if they are not yet sure what these should be. We saw that the maps added depth to searching the Web: pupils may be seeking a specific kind of data to complete a map, or when unexpectedly encountering a potentially relevant page, they must now reflect on how to link it in coherently to their narrative.

Reviewing this work, O'Brien (personal communication) stated "mapping has its strength in that the pupils can determine for themselves the links that make the knowledge intelligible, through conceptual bridges they can make in their own minds, and in this way their learning skills are greatly enhanced. For these pupils, this allows them to develop strong strategies for learning like chunking, and skills to develop thinking in depth".

Scientific writing and mapping

The pupils we worked with clearly did not see writing as particularly enjoyable or central to science. It is likely that this naïve separation between what might be paraphrased as "doing the real science" versus "merely communicating it" is widely shared in the general public, but is directly challenged by the work we briefly reviewed at the start, in which science is constituted by its different discourses, which in turn actively shape the work that is undertaken. Sociological theories aside, we have the intensely practical task of raising a generation who want, and have the skills, to engage in public debate about science-related dilemmas. Pragmatics confronts us with

the task of teaching pupils how to argue and reason critically, and convincing them that how and why scientists argue is deeply interwoven with what experiments they do and what can be concluded from them.

Since we are all schooled in writing prose from an early age, it is no surprise that writing essays or posting comments to a discussion forum came more easily to the pupils than mapping. This will always be the 'path of least resistance' — but as all teachers and researchers know to their cost, fluency with the language and the fluidity of the digital medium can simply serve as a channel for unfocused verbiage. As historians of orality, literacy and digital media note, greater resistance in an information environment can foster greater reflection before ideas are committed (Ong, 1982, Heim, 1987).

We have described some of the translations that we observed from maps to prose, with some indicative results that a good IBIS tree structure in a map assisted the subsequent linearisation task by generating a coherent document outline. Sometimes pupils wrote maps in anticipation of conversion to prose, using connectives in node labels, while others added them after, in order to translate the nodes and links into more flowing prose. A closer analysis is needed to investigate specific questions about how graphical connections in a mapping language relate to appropriate use of connectives in prose.

Moving in the other direction, we translated pupils' prose into maps for analytical purposes, but there were no activities that specifically scaffolded this, e.g. through teaching the systematic annotation of texts, as is supported more directly by tools such as Araucaria (Chapter X). Again, it is an open question as to whether young teenagers can be taught this, in the way that Reed et al have worked with university undergraduates.

Cartographic literacy

Prior work has documented the intellectual work involved in constructing dialogue and argument maps. The cognitive tasks (Buckingham Shum, et al. 1997) include parsing the flow of ideas at an appropriate granularity, assigning a node type (icon), labelling them succinctly, and connecting them with meaningful links to an appropriate node. Doing this in real time to capture a discussion in the graphical IBIS language is a specific skill that Conklin (2006) terms Dialogue Mapping, which includes a collection of heuristics for recognising different kinds of conversations and creating coherent, balanced maps. Selvin (Chap. X) takes this even further, examining expert performance when formal modelling and multimedia assets are added to the mix. In sum, like any advanced intellectual or artistic discipline (as cartography surely is), one starts simple, but there is great scope for mastery and beauty.

To a practised dialogue mapper's eye, the pupils' maps leave much to be desired in terms of form and content, but these are equivalent to the first stammering phrases in a new language. The question is to what extent dialogue mapping can add value even at this stage, in order to maintain pupil (and staff) motivation to use this new way of reading and writing ideas. Our case studies provide qualitative indicators that we take to be promising, although the story is clearly not straightforward.

The tasks of parsing one's thoughts into discrete nodes, and classifying with appropriate icons are possibly the most demanding, and examination of the pupils' maps (or, indeed, any dialogue map) highlights that there are no hard rules. Whether a node is considered objectively reported Data or a personal Idea varies; whether an idea is a Pro/Con or an Idea depends on how the root Question is framed. Whether a complex idea is left as one node or decomposed into constituents is again context dependent. The point is that concepts such as Problem, Answer, Data, Evidence are merely roles that elements play in discourse. At one moment, an idea is an unproblematic assumption, folded into a Question. That same idea may become an explicit Idea node somewhere else, or a Pro/Con. Pedagogically, this is of course an extremely complex point to teach any teenager, but this abstract concept is made tangible in dialogue mapping through the icons: the message is implicit in the visual language, if taught correctly. This brings us to the teacher's role.

The teacher's role

In any context, teachers must provide appropriately constrained activities in which pupils can accomplish meaningful work. Knowledge cartography's process-orientation can provide a 'window' into the workings of pupils' minds by showing the intellectual moves they are making more clearly than when it is embedded in prose. As one pupil commented, mapping makes it easier for the teacher to mark the work, and we saw a key role for teachers to provoke thinking by asking specific questions about maps. The science teacher working on the summer school commented, "Dialogue mapping can function as a teaching aid if this mapping technique is applied in a context of a project with a set of activities, where pupils can rethink their mapping, get feedback and improve it."

In terms of dialogue mapping, this translated in a number of ways, including drawing attention to a specific part of the map that lacks clarity ("what are your key ideas?) or needs elaboration ("where are the counter-arguments?"); focusing pupils on substantiating reasoning with evidence from the Web; as well as domain knowledge checks ("why will melted ice raise water levels?"). We see huge scope for developing a 'battery' of checks that both teachers and pupils could use to assess the quality of dialogue maps, adapting the work of Conklin and Selvin on the practitioner skillset to capture the heuristics in engaging, memorable ways.

Software design

We have discussed at some length the nature of the resistance that a diagrammatic language like graphical IBIS presents to the expression of ideas. In contrast, the mechanics of driving Compendium were unproblematic, with pupils comfortable with a familiar direct manipulation user interface for dragging, dropping and linking nodes and websites. Greatest problems were encountered in exporting maps to outlines, and sharing maps via the Moodle web environment, a process that has been streamlined since this summer school: Compendium now has a custom Moodle export that inte-

grades HTML Maps, Outlines and XML data versions, which can be uploaded as one file for processing by Moodle.

Of most interest to us is the match between how pupils give form to their thinking, and how this can be gradually structured, moving from an inchoate collection of thoughts equivalent to a sheet of sticky-notes, into a deliberation map that can be judged rigorous by scientific and argumentation standards. Central to Compendium's design has been a focus on avoiding "premature commitment" to inappropriate structure, and other key cognitive dimensions that determine the fluidity of tools for thought (Cognitive Dimensions 2007). We saw in the case studies the value of permitting freeform layouts of nodes, but also the danger that this low constraint condition can provide 'enough rope to hang yourself' with spaghetti link structures. We are concluding that predefined visual patterns in the form of reusable templates could have an important role to play in seeding maps with useful structures, establishing a visual language that makes tangible important intellectual lenses that we want to instill.

To summarise, we might pull together the above threads in a vision as follows. We want to reach the point where pupils and teachers feel as confident with knowledge cartography as they do with other digital tools, and where the visual schemes provide an intuitive way to build and critique reasoning using the cartographic language of colour and space, e.g. Where's the purple? (=there's no data); Where's the red? (=there are no counter-arguments); Why do these nodes all say the same thing? (=there may be a clearer structure to this map which groups these nodes together more elegantly); Where's the root node? (=what's the core issue at stake?); Why are these nodes out here on the edge? (=are they irrelevant to the rest of the argument, or are you missing an important question that will bring them in?).

Conclusion

Dialogue Mapping is a relatively mature knowledge cartography approach, with an established user community, technical base and codified training, with demonstrable value outside education. This chapter has discussed the results of a pilot investigation introducing it into a secondary school context, specifically in response to growing concern over pupils' poor scientific reasoning skills.

We have explained the relationship of scientific argumentation and Dialogue Mapping, and presented qualitative analysis of three case studies from a UK summer school for teenagers aged 12-13 years. We aim to continue investigating the research questions introduced above with respect to how Dialogue Mapping and Argument Mapping can be used to improve pupils' critical thinking and argumentation skills in contemporary socio-scientific debates.

Our objective in terms of professional development is to foster a community of practice (in the OpenLearn project – figure 9) amongst educators and researchers (and perhaps even pupils), with its own focused workshops, online discussions and the sharing of curriculum ideas.

We welcome contact from all who would like to participate in such a network.

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