Representations of Conception:
Towards a Repertoire for Thinking and Learning

Tom Conlon†
Steve Gregory‡

†School of Education, University of Edinburgh
tom.conlon@ed.ac.uk
‡Department of Computer Science, University of Bristol
steve@compsci.bristol.ac.uk

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conception
noun
the way in which something is perceived or regarded : *our conception of how language relates to reality.*
• a general notion; an abstract idea : *the conception of a balance of power.*
• a plan or intention : *reconstructing Bach's original conceptions.*
• understanding; ability to imagine : *he had no conception of politics.*
(from Oxford American Dictionaries)

Abstract

Building an external representation of our conceptions is an important way to learn, communicate, and solve problems. Although some forms of representation are idiosyncratically tied to particular school subjects and topics, there are others that have multidisciplinary scope and broad utility for thinking and learning. In this paper we argue that in a wide range of curriculum contexts it should be possible to boost critical thinking skills, problem-solving power and learning capacity by the consistent adoption of a well-selected repertoire of forms of representation. We review a set of five specific forms of representation, namely argument maps, concept maps, writing plans, swot maps, and thematic maps, that seem promising candidates for such a repertoire, and we describe the design principles that underpin *Conception*, a versatile information mapping program that we have developed to support this set. The paper concludes by discussing forms of associated classroom practice that are consistent with current theories of effective teaching and learning.

Introduction

The movement towards ‘thinking skills’ in education has acquired much momentum in the last couple of decades. And with good reason: the internet and other electronic media have produced an explosion of information that both reflects and catalyses immense changes in the patterns of personal lives, local communities, workplaces, and national economies alike. Success in this context often depends upon the capability to sift and transform a mass of competing information sources into coherent, productive personal knowledge. Education policy has shifted accordingly. Forty years ago, the sort of student whom teachers often rewarded best was 'the quiet non-thinker' (Raths et al., 1966). Nowadays, governments advise teachers to promote positive contributors and successful learners (DfES, 2003; Scottish Executive, 2004).

A great deal has been written about how thinking skills can be framed, taught and learned (see McGuinness, 2005, for a review). The particular focus of this paper is on the key idea of *representation*. As McKendree et al (2002) have pointed out, the development of thinking skills requires techniques that enable teachers and learners to represent their thinking visibly. Our central claim, which is quite strongly supported by available evidence, is that a modest repertoire of forms of representation can satisfy this requirement for a broad range of tasks and subjects. The repertoire that we identify, together with the technology that we have developed to support it, should equip learners generically for tasks such as arguing, summarising, evaluating and planning. An important benefit of this approach is that, because the forms of representation are endlessly re-usable, the thinking skills that are associated with them should transfer into contexts beyond those in which they are first introduced.

The main purpose of this paper is to justify these claims and to stimulate forms of research, including action research, that can further explore them in practice. The paper is written so as to be accessible to a very broad audience, so that it can be read variously as a tutorial, research review, or proposal for further work. Its structure is as follows. The first part describes the relationship between thinking, representing and learning, explains the relevance of the notion of a repertoire of forms of representation, and specifies the contents of a repertoire that seems to provide at least a good starting point. Next, we present the design principles that underpin *Conception,* a versatile information mapping program that we have developed to support the repertoire. Finally, we discuss forms of associated classroom practice that are consistent with current theories of effective teaching and learning.

Thinking, representing and learning

As we learn, we build conceptions of our world. Mostly, these conceptions are represented only by mental structures which are, of course, invisible. Making conceptions visible requires that they be expressed externally, in some form of notation: examples are text, diagrams, maps, and musical scripts. Notations vary greatly in form and in fitness for different tasks and contexts but they share this central purpose of 'making thinking visible', or in other words, of making external representations of conception (Peterson, 1996).

Why are external representations useful? They serve many purposes: they act as records of and extensions to our memories; they allow conceptions to be communicated socially, which enables them to be shared, discussed and developed collaboratively; they can assist problem-solving by providing focus on essential, rather than peripheral, features of information; they provide a framework for acquisition of further information; and often, they suggest ways in which information might be transformed. In summary, external representations are essential tools of thinking and learning. Education is often understood as being about building conceptions but to have a conception that we are incapable of expressing is hardly useful. Thus in practice, much of education is concerned with learning to use forms of representation.

It is interesting to consider the relationship between our conceptions, their external representations, and the actual world that is represented. For example, consider the map that we might draw to show some visitors to our town how to reach our house from the railway station. We have a conception, one that is certainly detailed and complex, of the town: thinking about it produces the map, an external representation that stands in place of the town; the town itself is the represented world (see Figure 1). At each step of building the map we must ask reflective questions: Is the map true to our conception of the town? Is it an accurate model of the town in reality? Is it fit for its intended purpose of communicating the route to our visitors?

Building an external representation is an important way to learn. The act of preparing one forces us to think about what we know, to select and organise our knowledge, and to consider how that knowledge can be conveyed to others. We become aware of the strengths, gaps and inconsistencies in our own knowledge. These metacognitive effects may be even more significant when the representation is developed within a social context, in which differences as well as similarities of individual conceptions are exposed and discussed. We may be motivated to check our facts, accommodate other people's viewpoints, and adopt new perspectives. As we practice our skills in representation, it is unavoidable that we also reflect upon our conceptions of the represented world.

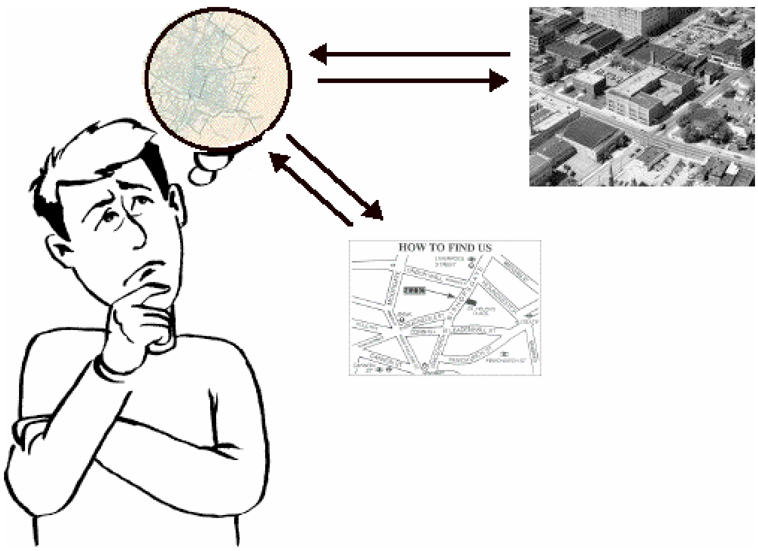

Figure 1 Conception, external representation, and the represented world

Repertoire

The form of representation that still dominates education today, just as it has done in the past, is text. This is not surprising: even in the age of the internet, text encodes most of the world's knowledge. Text can express complex ideas, it is hugely versatile, and it is well supported by technology including printing presses, word processors, and electronic mail. But text is not ideal for all purposes. If it were then we would have no reason ever to use maps, diagrams, or musical scripts. Of course, the information contained in a map (for instance) could in principle be re-represented wholly as text but the conversion process would be laborious and the most likely result would be a representation that would be much more difficult to understand, extend, and discuss.

All representations are not equal, even if their information content is the same. A superior form of representation for a particular type of information is one that makes salient features of the information easier to express, interpret and manipulate. It should be fit for the user, fit for the domain, and fit for the purpose (Peterson 1996). These are challenging criteria and humans have been enormously inventive in creating a vast array of specialist forms of representation. Think for instance of the thousands of computer languages and mathematical notations, or the numerous types of spatial map devised by cartographers. Becoming proficient in the disciplines of computer science, mathematics and cartography is very much about mastering these specialist forms. Much the same could be said about other disciplines, all of which have their own repertoires of representation.[1]

'Literacy', which is usually understood as a set of skills in reading and writing forms of text, is justifiably placed at the centre of education because these skills are essential across practically all disciplines. But a preoccupation with text should not obscure the fact that for some users, domains and purposes, alternative forms of representation are superior. In fact, a characteristic of good problem-solvers is that they have a broad repertoire of representational skills. When faced with a new problem, they can often select from the repertoire a form of representation that is immediately useful in organising the available information. If efforts towards a solution reach an impasse then switching to an alternative form of representation, assuming the repertoire makes one available, can provide a way forward (Cox & Brna, 1995). Understanding of representational features and of ways in which different problems have underlying representational similarities is the key to making learning from one problem transfer to another (McKendree et al, 2002).

The converse is also true. A weak representational repertoire can block thinking and learning because new information cannot readily be accommodated. A task such as preparing an argument, summarising a text, evaluating a proposal, or planning a piece of writing, may seem deeply formidable to someone whose personal repertoire does not include forms of representation that are well suited to the task. Of course, arguing, summarising, evaluating and planning are universally perceived as essential skills. Therefore, forms of representations that flexibly support such skills, and which are relatively easy to learn, offer multidisciplinary scope and broad utility for thinking and learning. Yet, beyond the established focus upon text-based literacy, the existing curriculum is far from systematic in supporting learners to develop the necessary representational competences.

Information maps

A helpful step forward may be to identify some forms of representation that could contribute towards a 'core repertoire' for education (we have in mind mainly primary and secondary education), one that could be invoked by teachers consistently and repeatedly in suitable contexts. Skills in interpreting and manipulating these core forms could become a shared curriculum goal, with many potential benefits. Learners who have the opportunity to apply the same representational forms to different subjects and topics can be expected to boost critical thinking skills, problem solving power and learning capacity. Teachers who know that an agreed repertoire of representations is being promoted across the curriculum could use the repertoire in communication and task-setting without having to teach basic concepts of representation from scratch.

The next few sections of this paper review some forms of representation that seem good candidates for inclusion within such a core repertoire. These are namely, *argument maps, concept maps, writing plans, swot maps,* and *thematic maps.* All are members of a class of diagram that is variously described as 'node-and-link diagrams', 'knowledge maps' or (our preferred term) 'information maps'. Each can be

[1] A distinction preserved by many authors, for instance Peterson (1996), is between a 'form of representation' (FOR), which refers to a particular notational convention (such as the concept map form), and a 'representation', which is a particular instance or example of the FOR applied to some domain (such as 'my concept map on minibeasts'). Although this is an important distinction, in this paper wherever the context makes the meaning clear we often relax it for brevity. For example, we refer to 'repertoires of representation' as shorthand for 'repertoires of forms of representation'.

regarded as a special kind of language, or what (Horn 1998) terms a 'visual language': a notation that combines text with graphics in some systematic fashion. As will be demonstrated, all five meet the criteria of multidisciplinary scope and broad utility for thinking and learning. Available evidence shows that they can be powerful resources for arguing, summarising, evaluating and planning.

There are additional reasons for taking these information map representations seriously. First, there are obvious trends in the media and in wider culture towards more varied and visual styles of communication. This means that skills in building and interpreting visual forms of information will become more important, not only for education but also for media literacy, citizenship and lifelong learning. Second, computers with graphical capability have become relatively ubiquitous. This is significant because capable computer software for information map creation and editing, such as the *Conception* program (discussed later) that we have developed to support our repertoire, can be hugely supportive and motivating. Third, teachers are becoming increasingly aware that deep, meaningful learning requires not only that learners engage with information actively, which means building their own representations as well as interpreting those of others, but also that learners differ in their individual thinking and learning 'styles'. Some learners, perhaps those whose cognitive styles are more strongly visual, may be more comfortable with graphical representations than with text, and more comfortable with some graphical representations than others. This is another justification for pursuing multiple representational forms, and for acknowledging that text is not always best: a pluralist approach acknowledges that diversity is natural and complex. It has its origins not only in the widely varying domains and tasks that learners encounter but also in the differences that exist between learners.

Argument maps

An argument map (see Appendix A.1, page 15 for an illustration) captures the structure of an argument or debate. Shaped as an upside-down tree, the map shows the central theme or 'main claim' of the debate as the node at the tree's root. Other levels show a hierarchy of claims and counter-claims that provide reasons for believing or disbelieving the claims to which they are attached. Ultimately claims should be grounded in evidence, which could be of various kinds such as (for example) eyewitness testimony, personal experience, or expert opinion. This is the function of the nodes labelled 'G' (for 'Grounds') in the illustration.

Argument mapping is a relatively new technique the roots of which are commonly attributed to (Toulmin, 1980). In our observation, it is still largely unknown amongst teachers. But the potential benefits of this form of representation are considerable, as research has demonstrated (Kirschner *et al* 2003, Twardy 2004). With an argument map, we can clearly identify the claims and rebuttals of a debate and we can see how these are related. The explicit requirement for evidence encourages critical thinking and the distinctive colour-coding of nodes[2] supports systematic comparison of different sides of the argument. As the map develops, it provides a concrete record of the state of debate thus far and offers a structure which can stimulate and accommodate new contributions, whilst discouraging repetition. An argument map may not ultimately 'resolve' a debate — among other reasons, because

[2] Colour-coding is a feature of most computer-supported argument mapping. For example, Conception automatically colours green and red those nodes that represent the 'pro' and 'anti' sides of the argument respectively. However, there are variations between argument mapping systems.

it does not do the complex work of weighing the evidence that is presented — but it by making visible the thinking that lies behind different lines of argument, it can take us part way there.

A striking feature of argument maps is their 'malleability': ideas can be restructured very rapidly. This is a major advantage over discursive text. If an argument map is something like plasticine, discursive text is more like fired clay or cast bronze. And as this metaphor suggests, the two forms of representation can complement one another. Argument mapping is a useful activity in its own right but it is also an excellent prelude to the creation of discursive text since it provides focus for the early 'idea-organisation' stage that is known to be crucial to a discursive text's subsequent development (Isnard & Piolat, 1994).

Concept maps

A concept map (see Appendix A.2, page 18) is a diagrammatic network in which nodes represent objects or events and links represent relationships between them. Typically then, the labels on nodes are nouns or noun phrases and the labels on links are verbs or verb phrases. Thus the triple of labels that can be read from a node plus its link to another node corresponds to a statement or proposition.

Like other information map types, concept maps are malleable, 'bare-bones' models of knowledge which offer visual appeal with none of the syntactic fussiness of (prosaic) text representations. They differ from other types in having extremely relaxed expressive constraints, which means that they can be applied to a vast range of domains and tasks. Indeed, if we agree with (Novak & Canas 2006, p2) that 'concepts and propositions are the building blocks of knowledge in all fields' then concept maps effectively provide a universal language for knowledge. Concept maps have a direct foundation in Ausubelian epistemology, which emphasises (in short) that development of well-integrated cognitive structures requires a process of 'meaningful learning' that must build on the learner's relevant prior concepts and propositions, acknowledge that these are idiosyncratic and progressive, and enlist the learner's active participation. Concept mapping by learners, whose individual maps reflect their own personal understanding, can both assess and progress a process of meaningful learning.

A large body of available research broadly confirms the utility of concept mapping across numerous domains and tasks, including teacher's planning, individual and collaborative learning, text summarisation and comprehension, and formative assessment (see for example Canas, Novak & Gonzilez, 2004; Canas & Novak, 2006). These successes have led researchers to encouraged a very broad uptake of concept mapping, including the call for 'a concept-map centred learning environment … where the concept map is used from the beginning of a unit to determine how much a student knew beforehand, through the unit as a means for researching and linking resources found or created by the student, until the map shows at the end how much the student has learned about the topic' (Canas & Novak, 2006, p3). Such proposals however also raise questions not yet fully explored, including learner differences and reliability of assessment in relation to concept maps.

Writing plans

A writing plan captures the intended structure and key ideas of a text, which could be a discursive essay, a factual report, or a piece of creative writing. As an example, Appendix A.3 (page 19) shows a writing plan that was created for the paper you are reading now. The plan is tree-structured with the document's proposed title at the root node. Nodes below the root show section headings or main ideas. Attached to these are nodes that identify subordinate ideas. Hyperlinks (shown as chain-like icons) can be attached to any node so as to give access to web pages and other online resources.

Writing is a complex process that typically interleaves activities of planning, sentence composition and revision (Flower & Hayes 1980). Explicit planning, which includes setting goals and selecting and organising main ideas, is a feature of many proficient writers, for whom plans provide essential guidance for composition as well as enabling evaluation of the text for revision. In contrast, novices and weak writers tend to minimise the role of planning in favour of 'writing down what they know'. Children's development of writing skills has been characterised as a shift from this 'knowledge telling' strategy to one of 'knowledge transformation' in which they become more conscious of, and devote more effort to, selection and sequencing of ideas, in other words, to explicit planning (Bereiter & Scardamalia 1987).

Writing plans can take various forms, such as text outlines and index cards. The effectiveness of an information map representation compared to these other forms remains to be explored. However, a writing plan expressed as an information map does have attractive qualities. It organises graphically a selection of ideas and supports via hyperlinks access to relevant materials. Since planning, composition and revision are recurrent and not merely sequential activities, it is desirable that any plan can be reworked as the text is composed. The information map representation is malleable enough to support this process, which should encourage iterative comparison between the map's state and the current state of text, or in other words, effective self-monitoring.

Swot maps

Business organisations for many years have used the swot method as a tool of strategic analysis, particularly in the early stages of decision-making. The acronym (which normally appears in upper-case form) stands for *Strengths, Weaknesses, Opportunities, Threats,* and the method amounts to little more than a listing of factors under these four headings. The origins of the method seem to lie in the work of US business policy academics, notably from the Harvard Business School in the 1960s. These academics popularised the idea that good strategy means 'ensuring a fit between the external situation a firm faces (threats and opportunities) and its own internal qualities or characteristics (strengths and weaknesses)' (Hill & Westbrook, 1997). Since that time use of the method has spread into many non-business settings. A Google search for "swot analysis" produces well over 1 million results, with applications that cover not only strategic analysis of many types of organisations but also evaluation of plans, proposals, and situations.

An example of a swot map is shown in Appendix A.4 on page 20. As with other forms of information mapping, the potential benefits of creating such a map stem largely from the metacognitive side-effects. As Puntambekar (1995) and others have observed, metacognitive effects are of two main kinds. The first is *knowledge about cognition* and the second is *regulation of cognition.* Making the swot map requires us to reflect upon what we know, which in turn increases our knowledge of our own mental resources (knowledge about cognition). Since the swot map directs our focus towards strategic concerns, it can help to develop our awareness of plans, goals, and checks (regulation of cognition).

Whether these benefits are realised in practice depends in part on the circumstances in which the map is produced. There is some evidence that, in business settings, the swot process is sometimes superficial and has little impact on subsequent policy-making (Hill & Westbrook, 1997). To ensure an effective swot process, researchers typically recommend well-facilitated group collaborations, clear statements about the aims and scope of the activity, return to and revision of the analysis beyond the first draft, and making explicit the links between the analysis and subsequent decision-making.

Thematic maps

A swot map articulates four prespecified aspects of an organisation, proposal or situation. A thematic map generalises this idea to any theme, leaving the map creator to identify the aspects. For example, the map shown in Appendix A.5, page 21 presents *Information mapping* as the theme and articulates the theme using aspects such as *Technology* and *Pedagogy*. The map appears as a wheel in which the theme forms the hub, with spokes radiating to the aspects. The central node is typically hyperlinked to relevant web sites and other resources. Other nodes can have hyperlinks too, of course.

Like concept maps, thematic maps are very widely applicable. The central theme could identify any area of knowledge or culture, including any topic in any curriculum at any level. The very simple radial layout together with the use of labelled boxes for the aspects provides a basic organising framework that can be widely adapted for teaching and learning, for example as a teacher's visual aid or to support learners in previewing or revising an area of study. A part-completed map may be a useful stimulus for classroom activity — for instance, consider a map which identifies the theme, provides some selected hyperlinks and the titles of a subset of the aspects, but with blanks elsewhere for learners to complete.

Summarising the repertoire

The repertoire discussed above is summarised in Table 1. For each map type is listed the types of thinking skills that are engaged, the main associated teaching and learning activities, the form of graphical layout, and the ontology (or conceptual framework) that is provided by the types of node. Looking at the columns that list thinking skills and activities, it seems clear that these map types offer multidisciplinary scope and broad utility for thinking and learning: in other words, they satisfy the criteria proposed earlier for a 'core repertoire' of forms of representation.

We do not claim that this repertoire is in some sense ‘optimal’. Although available research is extensive and supportive, it is incomplete. Furthermore, the diversity of users, domains and tasks is very large. No repertoire can be extensive enough to cover every possible representational context. An analogy is with learning words and phrases of a foreign language: a judiciously selected vocabulary will assist in many, but not all, situations. More learning may cover more situations, but with diminishing returns.

A fair question is to ask whether our repertoire is judicious. Minimalists may object for example that, since all of our map types are essentially specialised forms of concept map, concept maps are all that is needed. The premise here may be correct but the argument is dubious: a car is a specialised lump of metal but if the task is to travel along a road then the specialised item makes by far the better choice. Concept maps are tremendously flexible but the ontologies of the other map types are more purposeful for the tasks that they are designed to support.

Others may argue that the repertoire is too small, and that Venn diagrams, mindmaps, piecharts, topic maps, decision trees, or some other preferred forms of representation ought to be included within the core. There are certainly debates to be had here since, as observed previously, representations express conceptions and each educational community has its own ideas about the kinds of conception that are most important.[3] In practice, it is inevitable (and useful) that learners will be exposed to a vast range of more or less *ad hoc* forms of representation, corresponding to the specialised conceptions of different disciplines and teachers. But if they encounter nothing but *ad hoc* representations then they may never come to understand that some thinking skills and intellectual tasks are ubiquitous across curriculum boundaries. Opportunities to transfer learning will be lost.

	Thinking skills	Activities	Graphical layout	Ontology
Argument maps	Argumentation	Discussion, summarising argument, debating, planning and reviewing discursive writing	Top-down tree	Claims, reasons, objections, grounds
Concept maps	Description, analysis, explanation	Previewing and reviewing topic content, summarising texts, explaining how processes operate	Network — any topology	Concepts, relationships
Writing plans	Planning	Planning for writing	Top-down tree	Titles, sections, main ideas
Swot maps	Evaluation, decision-making	Analysing organisations, proposals, and situations	Radial network	Strengths, weaknesses, opportunities, threats
Thematic maps	Description, analysis	Previewing and reviewing topic content, communicating and presenting summaries	Radial network	Themes, aspects

Table 1 Summary of the repertoire

Technological support

We have developed a computer program, named *Conception,* to support the repertoire described above. For illustrations of Conception in use, see Appendix C, page 23. The rationale for the program is straightforward: teachers and pupils need technological support for the entire repertoire. This implies a combination of flexibility and focus that is unavailable in existing software. On the one hand, general-purpose drawing programs like *Inspiration* can in principle produce anything, but the price the user pays for this flexibility is high in terms of editing effort. On the other hand, high-quality programs such as *CMapTools* for concept mapping and *ReasonAble* for argument mapping, but they focus on a single map type. On the assumption that users would not want to learn several different programs, it was obvious that an information mapping tool directed towards the repertoire was needed.

Conception's design principles can be summarised as follows:

[3] The case of mindmaps is particularly interesting. Mindmaps are essentially radial networks without link labelling or other syntactical constraints that could make their meaning explicit. For instance, they lack the linking phrases that make concept maps interpretable as sets of propositions. Thus, to an external reader, a mindmap is likely to appear as an incoherent bundle of indeterminate associations. Compared to concept maps, mindmaps have a far weaker basis in research evidence but they have been heavily popularised with very strong claims (Buzan, 1996). Teachers may be more familiar with them than they are with concept maps (Conlon & Bird, 2004).

- *Productivity*: 'Smart' graphical editors are provided that recognise the distinctive graphical syntax of each type of map, so that map editing is highly productive. For instance, the argument map editor 'knows' what kinds and colours of nodes can appear below a given node and it uses this knowledge to offer options and take actions that correspond to valid extensions of the current map.
- *Extensibility*: Each map type is realised internally by a standardised and editable specification of its associated graphical layout and ontology, rather than by 'hard coding'. This means that Conception is easily extended to support new forms of representation, a feature that has been essential to us in investigating the repertoire.
- *Learnability*: Interaction protocols are consistent across map types, but with differentiation where necessary. For instance, the menu names and graphical tools for a concept map and argument map are identical, but the menu commands and tool functions vary according to the distinctive syntax and semantics of these types. The aim is to ensure that, having learned to use the program for one type of map, using it for other types becomes easier because most of the learning transfers.
- *Functionality*: Easy access to powerful mapping functions including hyperlinking capability, inserting graphical images, performing web search based on map content, and transfer of text between maps, phrase boxes and markup editors. For more experienced users, shortcuts to most functions are available.

Experience with actual users has indicated that these design principles are sound (Conlon 2003, Conlon 2006). Because Conception provides support at the level of each map's ontology, rather than at the more generic level of nodes and links, users are freed to concentrate on the content and organisation of ideas. Ideally, the tool should become 'invisible' (Norman, 1998) leaving focus entirely on the task. Although we still regard Conception as an 'early effort' that needs further investment and development, the program has clearly established the feasibility of providing software support for our representational repertoire.[4]

Classroom practice

However good a repertoire of forms of representation may be in theory, in practice a lot depends upon how well it is used. The research literature on the pedagogy of information mapping is not yet extensive. However, enough is known to provide some broad pointers towards effective classroom practice. For an overview of this area, see the concept map in Appendix B.

Type of task

An obvious distinction is between interpretation tasks, those that require students to interpret other people's representations, and generation tasks, those in which they generate their own. There should be scope for both types since they develop different kinds of skill (broadly, comprehension versus expression). Somewhere between interpretation and generation lies a type of task that we call

[4] Conception at present runs under Microsoft Windows and Macintosh OS X. See http://www.parlog.com for details of availability.

critiquing, in which the student is expected to evaluate or compare information maps. Critiquing goes beyond interpretation to include elements of evaluation. Sometimes (but not always) critiquing will involve the generation of new maps or the adaptation of existing ones.

We might expect that, other things being equal, activities which involve interpreting, critiquing and generating, correspond to ascending levels of challenge. But in reality, the degree of challenge in a mapping task depends also on two other factors: the extent of learner's familiarity with the domain (or subject matter) and the resources (including peer and teacher help) that are provided in support of the task. Thus a minimally challenging task may involve *interpreting* a representation in a *familiar* domain with *extensive* support. A maximally challenging task may involve *generating* a representation in an *unfamiliar* domain *without* any support. Generally, teachers should aim to design tasks which learners can accomplish with the provided level of support but which would have been beyond them without it (Vygotsky, 1987).

Interpreting an information map is not necessarily easier than interpreting a text. This is because text follows familiar conventions, including sequential access and the use of structural devices, such as headings and paragraphs, that provide clues in the interpretation process. Although information maps also have conventions — consider for instance, the highly stylised graphical syntax of an argument map — these are less familiar. Teachers can model the process of interpreting an information map by talk-aloud demonstrations and by probing with questions that ultimately can be internalised to provide the learner's own self-regulation, in other words a process of procedural facilitation (Collins, Brown & Newman 1989). For instance: What is this map's theme? How can we 'skim-read' it? What does the map say about such-and-such? What do the nodes have in common that use the smallest font? What other node could possibly have been attached to this node?

In tasks that involve generating an information map, three stages of activity can be usefully distinguished: *preparation* (including review of existing knowledge and research of source material), *mapping* (actual construction of nodes and links) and *revision* (including redrafting, assessment, and presentation or publication of the results). Support at each stage can take many forms, including help from peers and teachers. Support can also take the form of a 'kit-of-parts': this may amount to no more than a short phrase list or, at the other extreme, it could be a 'gappy' complete map that lacks only a few separately listed items. Support may also include reference materials for the domain, which could be a closed set of sources or an initial set of recommended sources with encouragement for wider exploration. One approach is to prepare and distribute to students a map that contains a single box to specify a focus question plus hyperlinks: see Appendix C for an illustration. According to Novak & Canas (2006), students who make concept maps without a good focus question tend to produce maps that are mostly descriptive. A good focus question encourages deeper engagement with the ideas and leads to maps that are more explanatory.

Critiquing activities can be quite diverse. Three examples: present learners with a preconstructed 'buggy' map, into which errors have been deliberately introduced, and invite them to debug the map using only their personal conceptions of the domain; provide them with an authoritative text, website or other source, plus a map that broadly summarises the source, but which contains anomalies that must be repaired; provide two information maps that pertain to the same topic but which deviate from one another in content and invite learners to comment on the differences.

Such activities have a strong problem-solving flavour. In some circumstances, map critiquing can be more effective than map generation (Chang, Sung & Chen 2002).

Organisation of learners

Information mapping activities can be tackled by individuals working alone or by pairs or groups of learners working in collaboration. Collaboration can be face-to-face or at a distance, using computer networks. In the case of distance collaboration, learners can interact either synchronously (i.e. in real time, as with chat software) or asynchronously (as with email).

Potentially, collaboration can enhance learning in at least three ways: it provides a supportive social context for tasks (teamwork), it can generate discussion in which conceptual differences are exposed and resolved, and it enables peer tutoring which develops the skills of both tutors and tutees. In classroom learning, where learners are diverse and teachers cannot hope to tutor each one individually, collaborative work can overcome some of the problems inherent in whole-class teaching. Studies of collaborative concept-mapping have generally confirmed that concept mappers who collaborate learn better than those who map individually (Basque & Lavoie, 2006).

However, productive collaboration implies more than just students working alongside one another. According to Ohl & Cates (2006), to design for 'real learning groups' requires attention to factors which influence group self-perception, interdependence and social-emotional bonding. For example, a group's perception of itself as a group can be strengthened by their knowledge of a common fate (such as a shared mark or grade), frequent meetings, and a 'name' that binds them together. Interdependence can be strengthened by a task designed so as to require the combined skills and efforts of the group rather than being achievable by individuals working alone. Social-emotional bonding requires time 'off-task' and consideration of ways in which group members can develop feelings of joint accomplishment.

In information map generation tasks, there are opportunities for collaboration at all three of the stages (preparation, mapping and revision) mentioned above. Task decomposition can include allocation of distinct research remits, creation of sub maps that can be subsequently hyperlinked or otherwise integrated, and rehearsals for joint presentation of the conclusions.

Assessment

A conventional distinction made in the literature is between *formative* assessment, which obtains information that helps students to improve their learning, and *summative* assessment, which obtains information that summarises what the student has learned. Formative assessment can include self-evaluation, feedback from peers, or guidance from teachers, whereas summative assessment is more closely associated with formal tests and examinations. We might also mention *diagnostic* assessment, which is aimed at obtaining information for teachers that helps to target teaching upon the existing state of students' knowledge.

Information mapping, particularly concept mapping, has been widely used as the basis of (mostly) formative and diagnostic assessment. For instance, Gouveia & Valdarez (2004) explain how the maps of high school students on a variety of chemistry topics revealed to their teachers certain weaknesses of understanding that they were able to target and rectify in subsequent teaching. Apart from this diagnostic assessment, concept map construction in this study also had a formative assessment purpose:

……. observations in the classroom showed that in attempting to verbalize his or her own idea on a specific subject with the intent of communicating this idea to others, students were forced to re-think and analyze what they wanted to verbalize, and, in doing so, were able to find further discrepancies and mistakes in their idea; that is, the student was forced to search for an alternate formulation for the same idea which, in turn, helped to broaden the student's point of view. The verbal interaction among students helped to keep them focused and, in some instances, to pay more attention to a classmate than to the teacher. (Gouveia & Valdarez 2004, $5.3).

In assessing the quality of an information map, some form of quantitative map scoring scheme may be useful. An early scheme for scoring concept maps was devised by Novak & Gowin (1984) and many variants have appeared since. An informal scheme for assessing argument maps is offered by Austhink (2006). More formal schemes usually depend upon a systematic comparison between a learner's map and a 'reference' map created by a teacher or other expert. This approach has been used to develop an artificial intelligence analyser which gives formative feedback and which relies on the learner's willingness to mediate the system's fallible judgements (Conlon 2004). For summative assessment, however, reliability is usually considered to be essential. This is certainly problematic for open-ended map generation tasks (Ruiz-Primo 2004).

Learning *with* versus learning *about* representation

In a rich and well-taught curriculum, learners should have many opportunities to build representations using the repertoire across a variety of subjects and topics. The cognitive apprenticeship model of teaching and learning (Collins, Brown & Newman 1989) provides a useful framework for thinking about how this learning can be supported. Starting from the observation that conventional schooling too often abstracts skills and knowledge from their uses in the world, resulting in surface learning, 'brittle' skills, and de-motivation, cognitive apprenticeship recommends a pedagogy that aims to re-connect theory to the contexts and tasks in which it becomes useful whilst at the same time gradually drawing students into a culture of independent practice. This pedagogy, which is inspired by traditional apprenticeship forms of learning, centres on the methods shown in Table 2. The third column of the table is our own interpretation of how the pedagogy can incorporate information mapping. The 'fit' between information mapping and cognitive apprenticeship is ensured by an explicit and shared concern to 'make thinking visible' and to promote effective metacognition:

Although schools have been relatively successful in organizing and conveying large bodies of conceptual and factual knowledge, standard pedagogical practices render key aspects of expertise invisible to students ….. cognitive and metacognitive strategies and processes are more central than either low-level subskills or abstract conceptual and factual knowledge. They are the organizing principles of expertise, particularly in such domains as reading, writing, and mathematics. (Collins, Brown & Newman 1989)

One of the principles of cognitive apprenticeship is that learning of theory should develop naturally from tasks and contexts in which the need for the theory is evident. Although there will be times when teaching will justifiably focus on issues of representation *per se*, an obvious example being when a member of the repertoire is newly introduced, in general this principle suggests a more integrated and holistic process of learning; one in which learning *about* representation will arise concurrently and naturally as a by-product of learning *with* representation. An integrated approach is suggested also by the empirical evidence that good knowledge and good thinking are inextricably bound up, implying that critical thinking is best taught in the course of teaching discipline knowledge (Pithers 2000).

	Teacher's role	Information mapping aspects of role
Modelling	Demonstrate the task or skill in a way that makes explicit the processes involved	Modelling the process of selecting a form of representation from the repertoire, building an information map, interpreting the map
Coaching	Observe students carrying out the task or skill; provide scaffolding (support) for parts that are beyond them; offer hints, feedback, new tasks	Coaching students in information mapping activities; designing such activities, including designing provision for support, collaboration and assessment.
Scaffolding and fading	Gradually withdraw the scaffolding provided previously; push the students towards independent problem solving	Gradually push students towards autonomous, self-regulated information mapping; progress from descriptive to exploratory and explanatory maps; support mapping in increasingly complex and diverse contexts
Articulation	Encourage students to articulate their knowledge, reasoning, or strategies	Providing opportunities for students to discuss their information maps; participate in presentations, debates and interviews
Reflection	Encourage students to compare their own knowledge, reasoning, or strategies with those of an expert or other performer	Get students to evaluate their own maps, critique the maps of peers, repair 'buggy' maps; get students to apply self-monitoring skills , including monitoring of their own learning by reviewing previous maps
Exploration	Push students towards independent problem identification and independent problem solving	Apply mapping to projects and more open-ended tasks; shift from teacher-directed problem-solving to student-directed problem-finding

Table 2 The cognitive apprenticeship model of teaching and learning

Conclusion

The movement towards 'thinking skills' in education has acquired much momentum in the last couple of decades. However, a problem that has been relatively neglected is that teachers both within and across disciplines have lacked systematic, transferable representational techniques that can make 'good thinking' visible. Learners who do not have good conceptions of representation will find it harder to produce good representations of their conceptions. Learners on the other hand who develop an effective repertoire of representations stand to gain ready-to-hand frameworks that will equip them well for tasks such as arguing, summarising, evaluating and planning. Transferability may be the greatest benefit, for although tasks are inevitably transient, and subject knowledge can be forgotten, the forms of representation are endlessly re-usable as a powerful resource for lifelong learning.

Although far from complete, available research indicates that the repertoire of representation that has been presented in this paper constitutes a useful toolset for thinking and learning. Complemented by effective technology, it offers an approach to classroom learning and curriculum development that school leaders and individual teachers should consider seriously.

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References

Austhink (2006). *Secondary Educator's Supplement*. Austhink Software Ltd. http://www.austhink.com, accessed June 11 2007.

Basque J. & Lavoie, M.C., (2006). Collaborative concept mapping in education: major research trends. In: Canas, A. & Novak, J. (Eds). *Concept Maps: Theory, Methodology, Technology*. Proc. Of the Second Int. Conference on Concept Mapping, San José, Costa Rica.

Bereiter, C. and Scardamalia, M. (1987). *The psychology of written composition.* Hillsdale, NJ: Erlbaum.

Buzan, T. (1996). *The Mind Map Book.* Plume/Penguin.

Chang, K., Sung, Y. & Chen, I. (2002). *The Effect of Concept Mapping to Enhance Text Comprehension and Summarization.* Journal of Experimental Education, 71(1), 5-23.

Collins, A., Seely Brown, J. & Newman, S. (1989). *Cognitive Apprenticeship: Teaching the Crafts of Reading, Writing, and Mathematics.* In: Resnick, L. (Ed) (1989). *Knowing, Learning and Instructing: Essays in honour of Robert Glaser.* Lawrence Erlbaum.

Conlon, T . (2003). Why Conception is better than Insipiration. *Proceedings of PEG2003, the Eleventh International PEG Conference on Powerful ICT Tools for Learning and Teaching,* St Petersburg, Russia, July.

Conlon, T. (2006). *Formative Assessment of Classroom Concept Maps: the Reasonable Fallible Analyser.* Journal of Interactive Learning Research, Conlon, T. Vol 17 No 1, pp.15-36.

Cox, R. & Brna, P. (1995) Supporting the use of external representations in problem solving: the need for flexible learning environments. *Journal of Artificial Intelligence in Education* Vol 6 No 2/3 239:302.

DfES (2003). *Every Child Matters.* Department for Education and Skills, Runcorn.

Gouveia, V. & Valdarez, J. (2004). Concept Maps And The Didactic Role Of Assessment. In: In: Canas, A., Novak, J. Gonzilez, F. *Concept Maps: Theory, Methodology, Technology.* Proc. Of the First Int. Conference on Concept Mapping. Pamplona, Spain.

Hayes, J.R., & Flower, L.S. (1980a). The dynamics of composing: making plans and juggling constraints. In L.W. Gregg & E.R. Steinberg (Eds.), *Cognitive Processes in Writing* pp 31-50) Hillsdale: Erlbaum.

Hill, T. & Westbrook, R. (1997). *SWOT Analysis: It's Time for a Product Recall.* Long Range Planning, Vol. 30, No. 1, pp. 46-52. Elsevier Science Ltd.

Horn, R. (1998). *Visual Language: Global Communication for the 21st Century.* MacroVU Press.

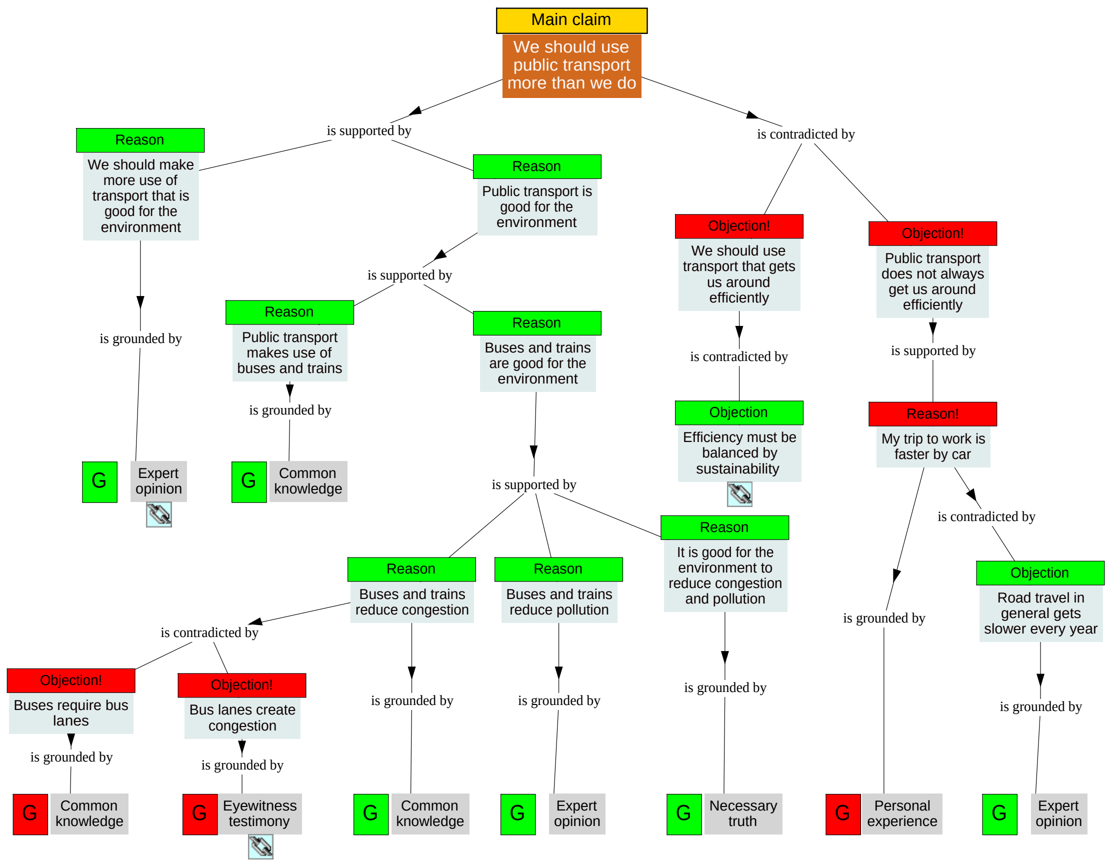
Isnard, N. & Piolat, A. (1994) The effects of different types of planning on the writing of argumentative text. In: Eigler, G. & Jechle, T. *Writing: Current Trends in European Research* pp121-132. HochschulVerlag.

Kirschner, P., Buckingham-Shum, S, Carr, C. (Eds) (2003). *Visualizing Argumentation.* Springer-Verlag.

McGuinness, C. (2005). *Teaching thinking: Theory and practice.* BJEP Monograph Series II, Number 3 - Pedagogy, 1(4):107–126.
McKendree, J., Small, C., Stenning, K. & Conlon, T. (2002) *The Role of Representation in Teaching and Learning Critical Thinking.* Educational Review Vol 54 No 1, pp57-67.
Norman, D. (1998). *The Invisible Computer.* MIT Press.
Canas, A., Novak, J. Gonzilez, F. (2004). *Concept Maps: Theory, Methodology, Technology. Proc. Of the First Int. Conference on Concept Mapping.* Pamplona, Spain.
Cañas, A. & Novak, J. (Eds) (2006). *Concept Maps: Theory, Methodology, Technology. Proc. of the Second Int. Conference on Concept Mapping*. San José, Costa Rica.
Novak, J. and Gowin, B. (1984). *Learning How to Learn.* Cambridge University Press.
Peterson, D. (Ed). (1996). *Forms of Representation.* Intellect Books.
Pithers, R. (2000). *Critical thinking in education: a review.* Educational Research Vol. 42 No. 3 Winter 2000 237–249
Puntambekar, S. (1995). *Helping students how to learn from texts: towards an ITS for developing metacognition.* Instructional Science Vol 23 Nos 1-3 pp163-182.
Raths, L. E., Wasserman, S., Jonas, A. And Rothstein, A. (1966). *Teaching for Critical Thinking: Theory and Application.* Columbus, Ohio: Charles-Merrill.
Ruiz-Primo, M. (2004). Examining Concept Maps As An Assessment Tool. In: Canas, A., Novak, J. Gonzilez, F. *Concept Maps: Theory, Methodology, Technology. Proc. Of the First Int. Conference on Concept Mapping.* Pamplona, Spain.
Scottish Executive, (2004). *A Curriculum for Excellence.* St Andrew's House Edinburgh, ISBN: 0-7559-4215-9
Sung, T. (2000). *The Effect of Concept Mapping to Enhance Reading Comprehension and Summarizing Abilities: a Comparison of Scaffolding Strategy, Correction Strategy and Self-generating Strategy.* Proceedings of AERA 2000.
Toulim, S. (1980). *The Uses of Argument.* Cambridge University Press
Twardy, C. (2004). *Argument Maps Improve Critical Thinking.* Teaching Philosophy.
Vygotsky, L.S. (1987). *The collected works of L.S. Vygotsky, Vol 1*. New York: Plenum.

Appendix A.1

Example of an argument map



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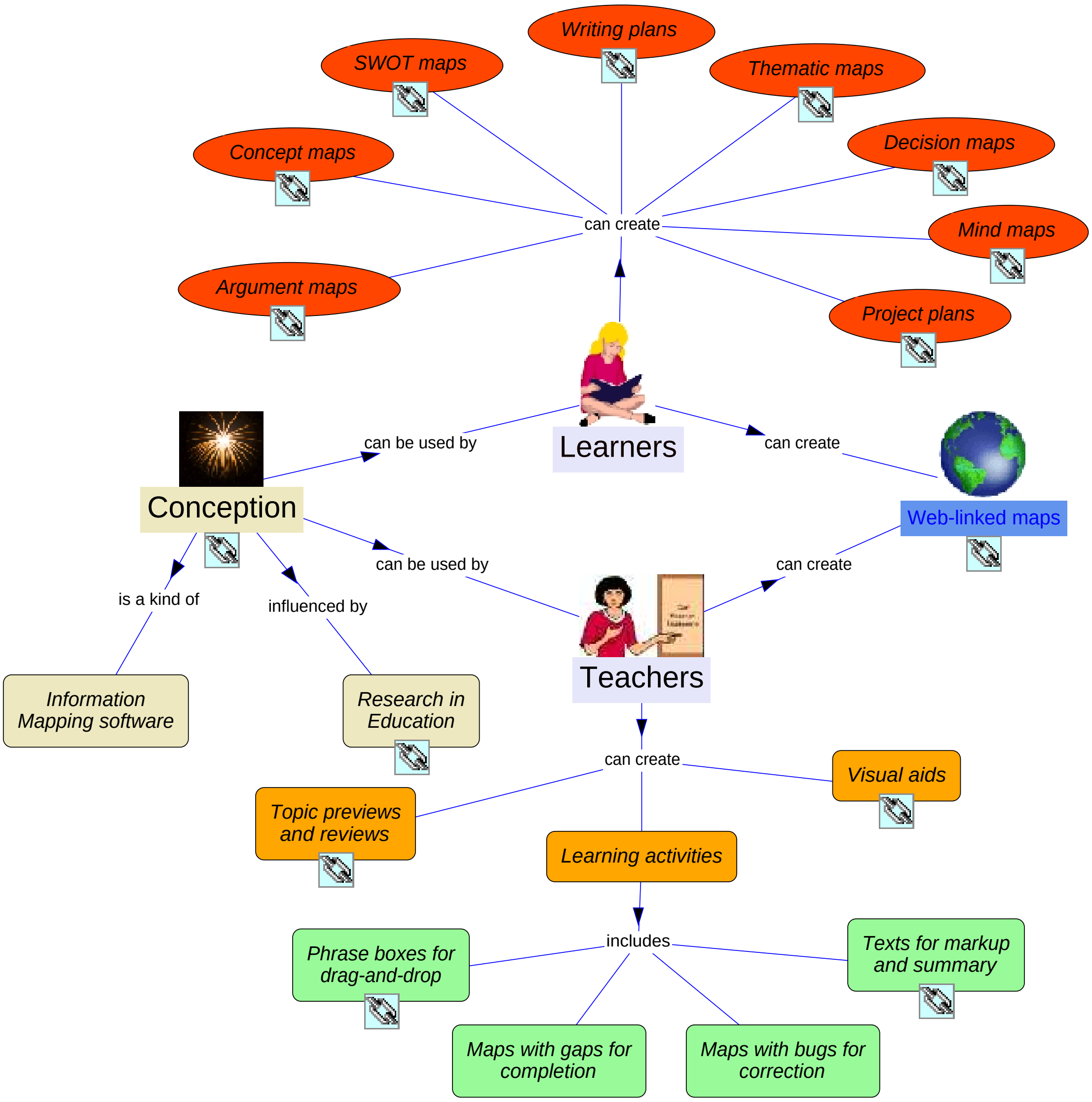
Appendix A.2

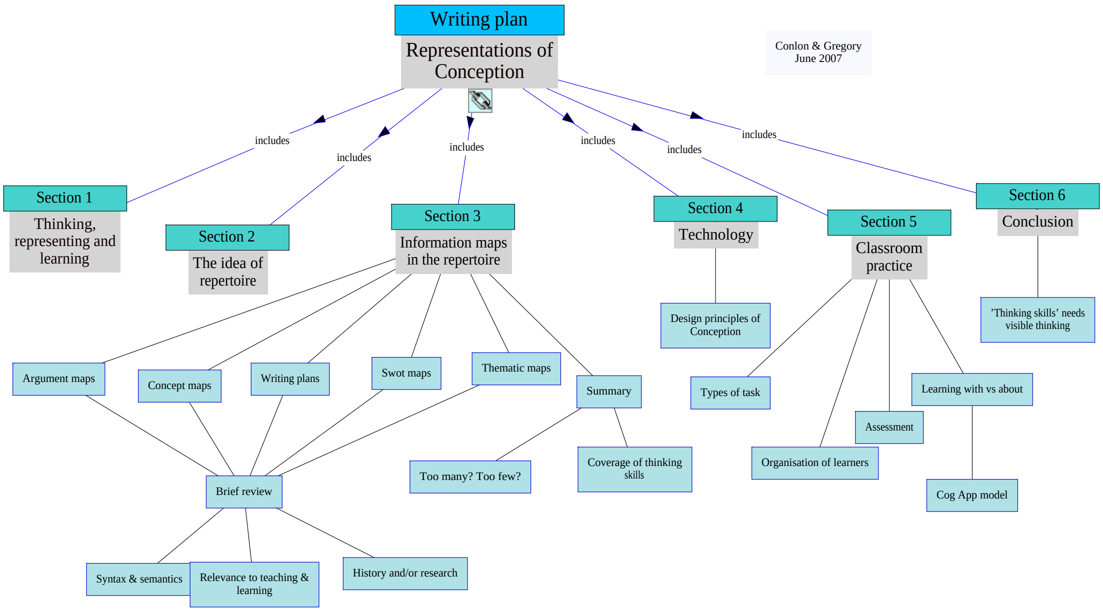
Example of a concept map



File: Conception/Examples/About_Conception.cpn

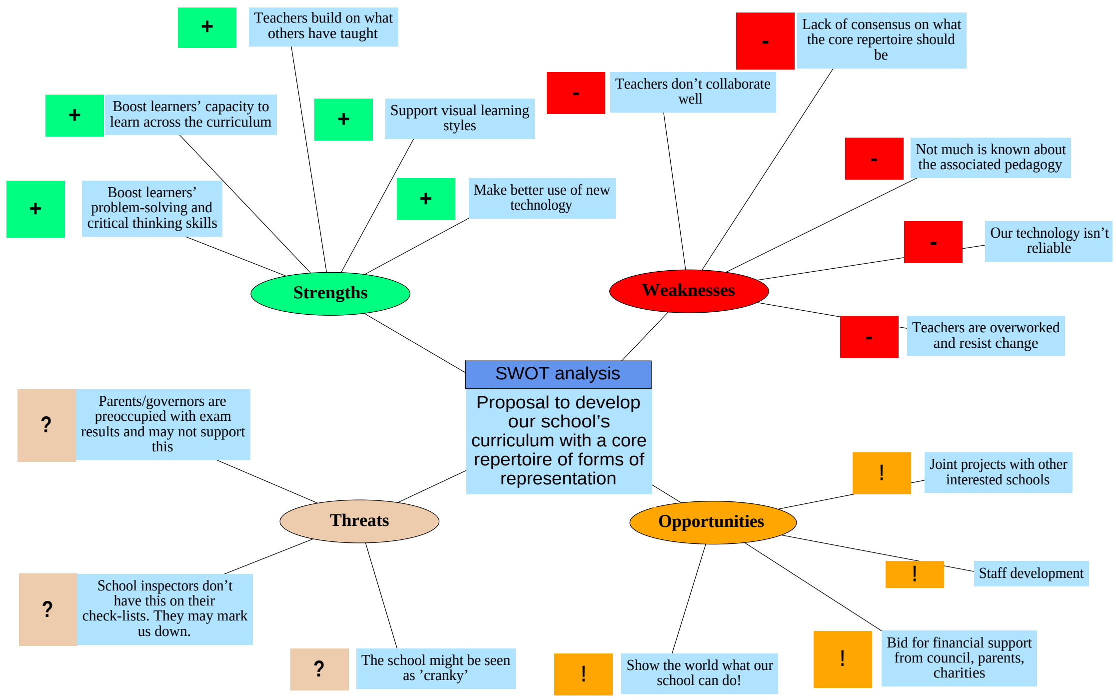
Appendix A.3

Example of a writing plan



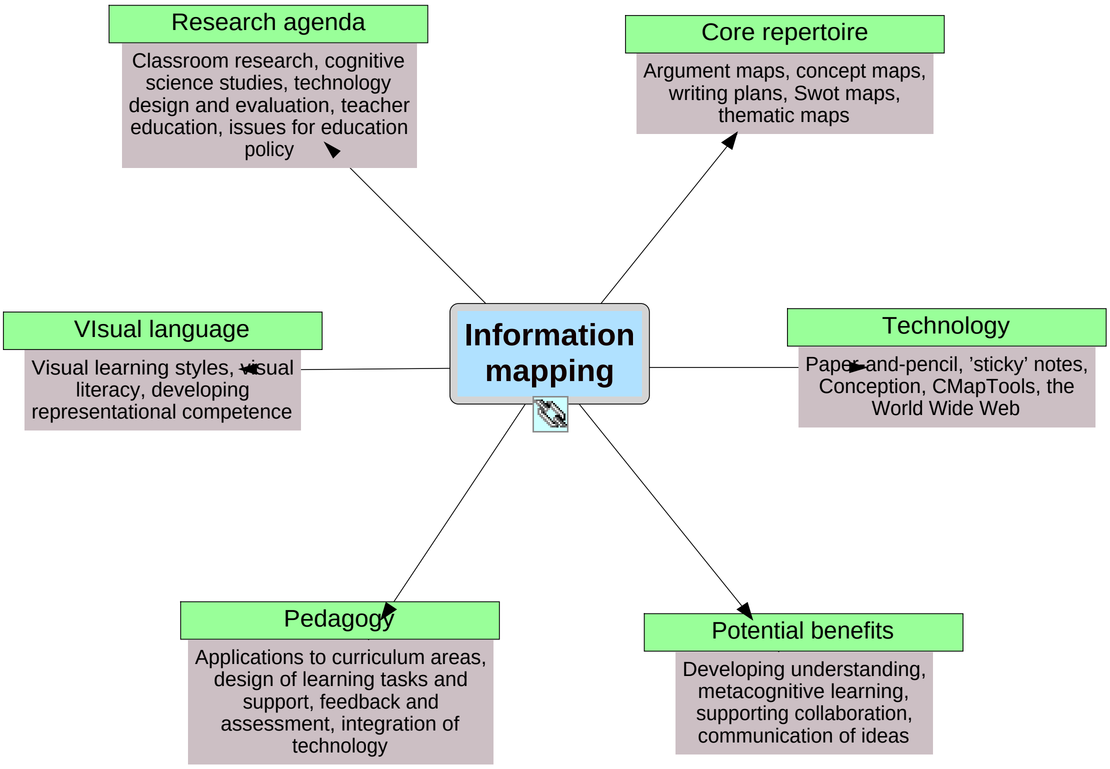
Appendix A.4

Example of a Swot map



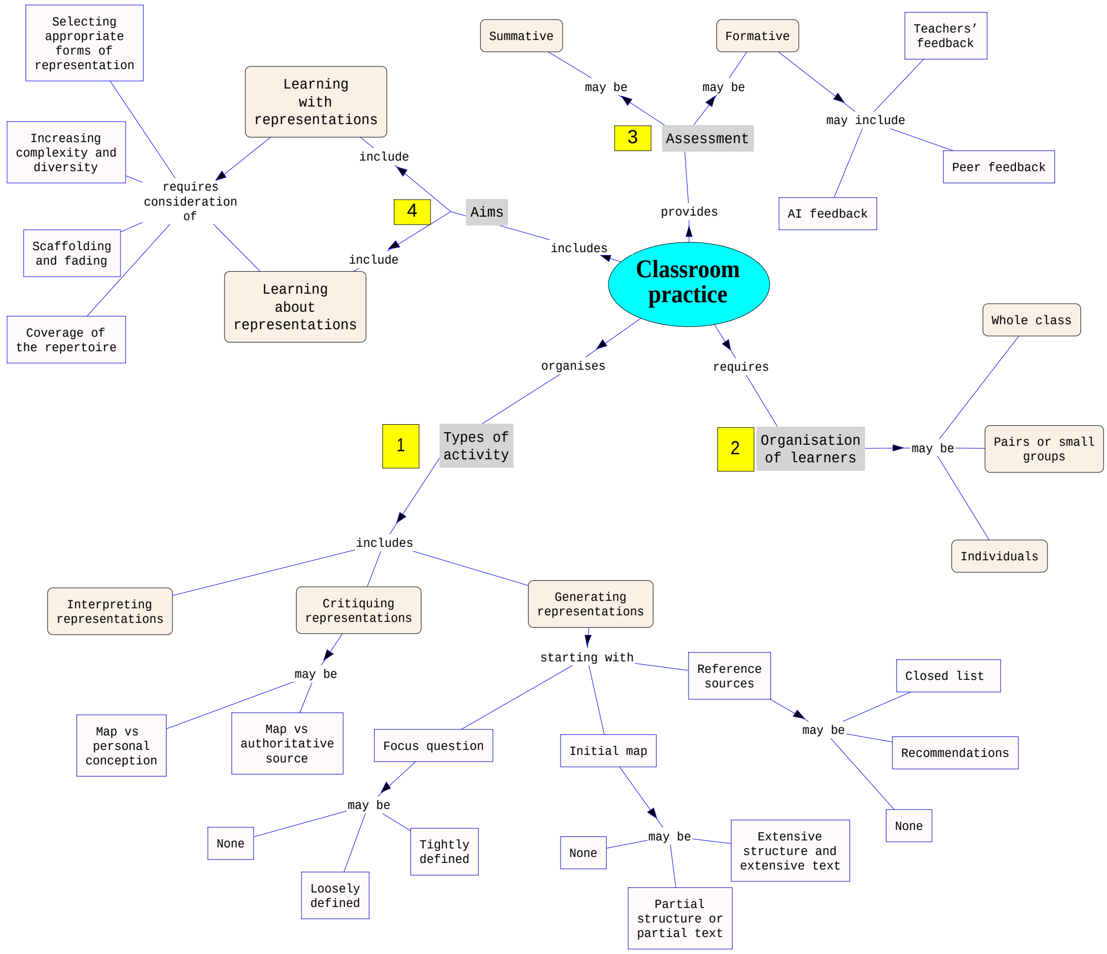
Appendix A.5

Example of a Thematic map



Appendix B

Aspects of classroom practice



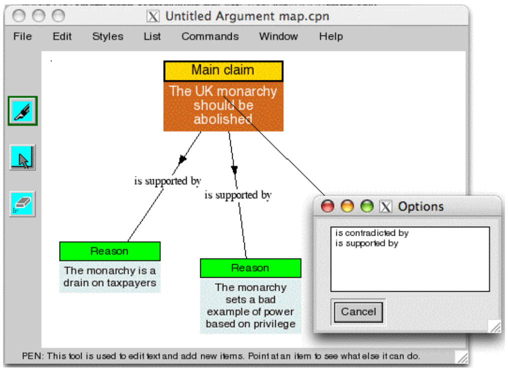
Appendix C

Using Conception software

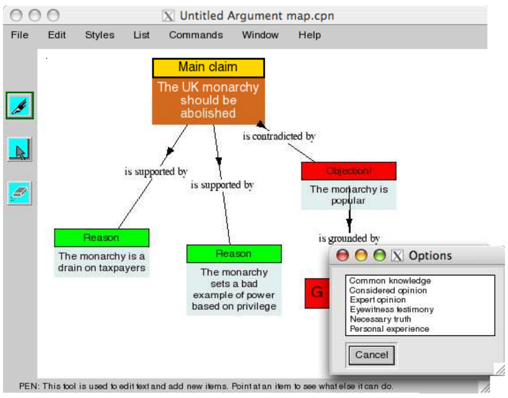
Creating a new window with the File/New dialog

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Adding a new node to the root node of an argument map by dragging with the Pen tool



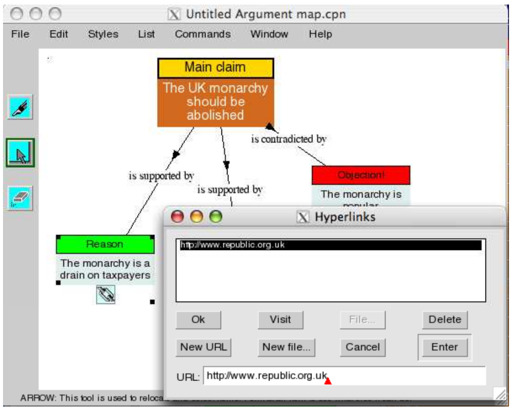
Dragging to add a new 'Grounds' node with the Options menu of evidence types



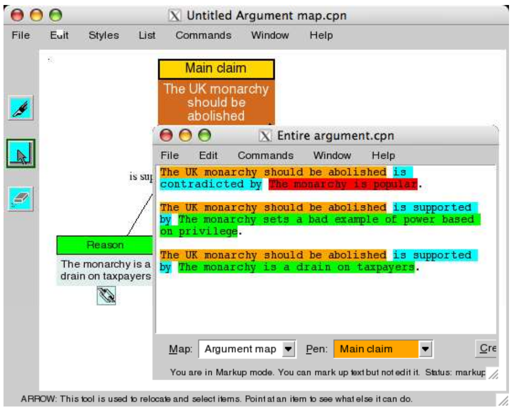
Setting up a web (Google) search via the Commands/Web_search command

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Adding a hyperlink via the Styles/Hyperlinks command



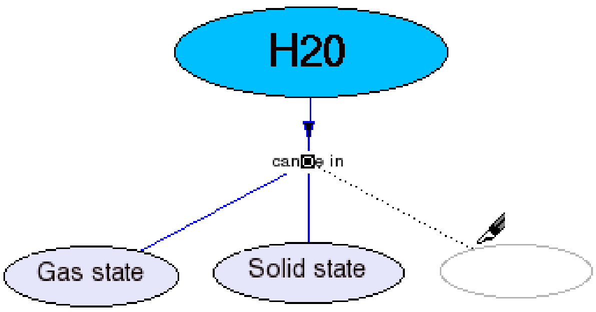
Generating a text representation of the argument via the List/Entire_argument command



Generating a Phrase Box via the List/Visible_labels command

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

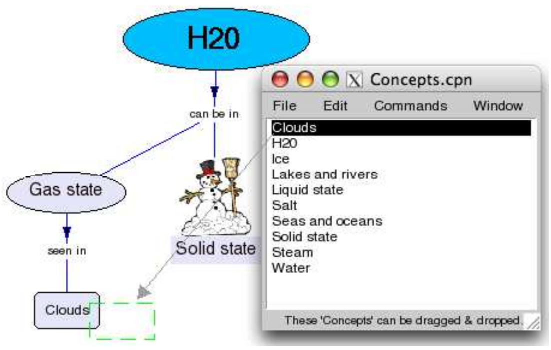
Attaching a node to a concept map by dragging with the pen from an existing link label ('split-linking')



Selecting a picture for a node via the Styles/Picture menu

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Drag-and-drop of text from a Phrase Box (created by List/Concepts) to a node



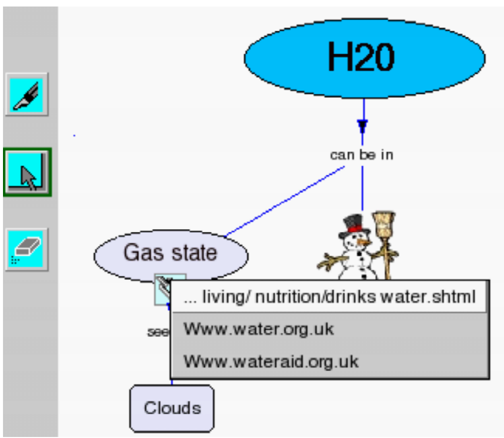
Using the List/Sentences command to extract a concept map's propositions

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

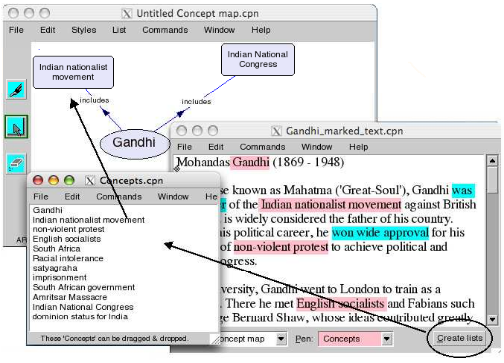
Adding hyperlinks to a concept map node via Styles/Hyperlinks

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Selecting a hyperlink to visit by clicking on the hyperlink icon (chain) with the arrow tool



Summarising a text in concept map form. The text is ‘marked-up’ in a Text Markup window, then ‘Create lists’ produces a Phrase Box of concepts that can be dragged-and-dropped into a concept map window



Using the Styles/Label_display command to conceal the text of a Thematic Map’s node

QuickTime™ and a
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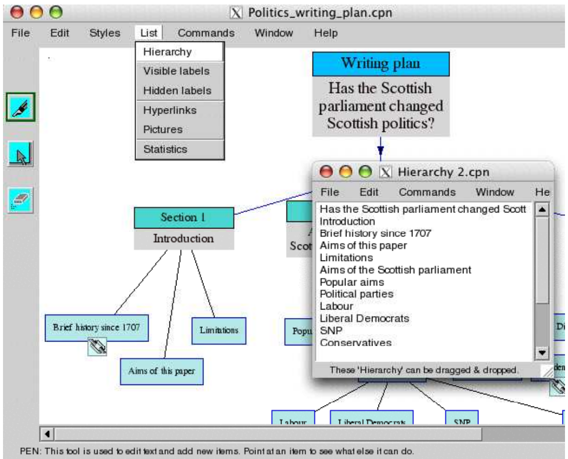
are needed to see this picture.

Extracting from a writing plan a text outline using the List/Hierarchy command



Supporting a task with a prepared window containing a focus question and hyperlinks

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Transferring the text outline into a text editor or word processor via that program’s Edit/Paste command

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.