The information design of ecological cycle network diagrams in science textbooks

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Abstract

Network diagrams of ecological cycles, *eg*, carbon and nitrogen cycles, are a common feature in science textbooks for 14-18 years age groups. From an information design perspective these diagrams raise a particularly interesting challenge; that of categorising up to six types of biological information using two graphic syntactic roles – nodes and connecting arrows – whilst ensuring an effective and unambiguous message.

This practice-led thesis reviews the precision of information categorisation in 209 network diagrams collected from UK and Danish science textbooks (1935-2009). Visual content analysis and graphic syntax theory (Engelhardt, 2002) is applied to review the existing information categorisation in relation to four types of graphic ineffectiveness: 1) implicit nodes, 2) imprecise relative spatial positioning of graphic objects, 3) polysemy, and 4) inconsistent visual attributes or verbal syntax. This review finds 29 types of ineffective graphic tactics, which may result in ambiguous messages due to illogical linking sequences, implicit circulating elements, and confusion about chemical transfer and transformations.

Based on these analysis findings, the design process in educational publishing is investigated. This identifies the rationale informing the transformation of information into network diagrams, based on semi-structured interviews with 19 editors, authors, designers, and illustrators in six publishing houses (3 in UK, 3 in Denmark). The rationale is mapped using phenomenographic analysis method and existing theories on the design process, namely brief development and translation stages (Crilly, 2005), choice points and the problem setting process (Schön, 2006), problem-solution co-evolution (Dorst and Cross, 2001), and design constraints (Lawson, 2006). The curriculum purpose of the ecological cycle network diagram is found to tightly constrain the identified rationale and the graphic decision-making based mainly on tacit knowledge.

In a final discussion the research findings are integrated by identifying models of design activities (Dumas and Mintzberg, 1993) present in the

investigated professional practice. This reveals how design decisions may influence the occurrence of ineffective graphic tactics. Recommendations for alternative information transformation strategies are then presented, centred on integrating graphic syntax knowledge into the current processes. These recommendations are anchored in suggestions by the interviewed participants.

Contents

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Notes on presentation and conventions

The term thesis here refers both to the argument presented in this dissertation and to the dissertation itself. Research enquiry refers to the research project and process from which the thesis is formed.

Note of references

The author-date reference system (Harvard) is used throughout this thesis. References for illustrations are included in the bibliography.

Note on illustrations

The ecological cycle network diagrams which are included to demonstrate the visual content analysis findings are presented in individual boxes with notes. This style of presentation is inspired by Engelhardt (2002).

List of abbreviations

UK	United Kingdom
n/a	not applicable
p	page
pp	pages
et al	and others
ie	that is
eg	for example

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2 Literature review

6 Current information transformation rationale

1 Introduction

Contents

1 Introduction

1.1 'Meta-reflection' on information design practice

This thesis presents an investigation of information design practice in educational publishing. Information design is seen as a design process and visual outputs which are focused on the effectiveness of graphic objects and their composition in relation to precise communication. Ecological cycle network diagrams – carbon, nitrogen and water cycles – are used as a case of information design visual output. This example is traced through its theoretical and professional practice context, to identify how design decisions may affect the effectiveness of graphic composition. In turn this demonstrates how information design theory and descriptive models of the design process might be used to enhance future practice.

1.1.1 Research strands

The graphic theoretical and professional practice contexts each forms a research strand, linked in an inductive path in this research enquiry. In the theoretical context, visual content analysis of 209 ecological cycle network diagrams reveals the potential theoretical complication when composing such diagram and identifies a range of ambiguities in examples from existing science textbooks. The analysis of the professional practice context is based on interviewing current practitioners. This analysis identifies the rationale guiding the process of transforming information – such as a manuscript and visual references – into an ecological cycle network diagram. Interrelations between the sets of research findings are then identified; revealing a set of plausible implications of design decisions on graphic composition, and in turn the message about the ecological cycle. These plausible implications form the premise for recommending an alternative information transformation rationale, centred on integrating information design expertise into the design process in educational publishing.

The analysis of visual output and professional practice context together constitute a practice-led research enquiry (Woolley, 2000) which is a 'meta-reflection-on-practice' (Cherry, 2005; Schön, 2006). Here a practitioner stands back and observes a specific area within a given field, aiming at making recommendations for improving aspects of future practice. In this case of research enquiry, a practitioner is reflecting on a field of practice – design practice in the context of educational publishing – in the UK and Denmark. This geographical focus is due to the researcher's involvement with design practice in both countries, and a wish to contribute to both. The overall aim of this 'meta-reflection-on-practice' is to demonstrate how practitioners may apply information design theory (Richards, 1984, 2000; Engelhardt, 2002) and descriptive models of the design process (Dumas and Mintzberg, 1991; Cross, 2000; Dorst and Cross, 2001; Crilly, 2005; Lawson, 2006; Schön, 2006) to review current practice, and utilise the findings to improve future practice.

1.2 Theoretical context of visual output

This section introduces the *first research strand* and the case of ecological cycle network diagrams; demonstrating how this research enquiry was prompted by finding ambiguities in existing examples. Graphic syntax is introduced as a theory for analysing the effectiveness of graphic composition. The network diagram is then linked to descriptive models of the design process; representing the design problem investigated in this research enquiry.

1.2.1 Visual output: ecological cycle network diagrams

The ecological cycle network diagram was chosen from a broader range of visual output from educational publishing, *ie,* student textbooks, the teacher manuals, exercise books, revision guides, web sites, interactive PDFS, web-based animations *etc.* This choice narrows the focus of this research enquiry to detecting compositional patterns in print-based ecological cycle network diagrams ranging from 1930-2009. This research focus contributes a reflection on lessons which may be learned from the print-based graphic palette, to inform future practices in both print and digital formats.

As a case of visual output, ecological cycle network diagrams offer particularly rich ground for studying information design practice. Ecological cycles include a range of elements – information types – with different biological nature, *eg,* organisms, processes, matter, and their different interrelations centred around continuous recycling of matter. When explained visually in a network diagram, these diverse information types are represented using arrows and nodes (Engelhardt, 2000:40). At higher scientific levels, *eg,* 'systems biology', the complexity of presenting ecological cycle content in a network diagram presents a 'formidable challenge' (Kitano *et al*, 2005: 169). This often results in diagrams, in which visually similar arrows have several different meanings, leading to ambiguous messages about the ecological cycle subject (Le Novère *et al*, 2009). When ecological cycles are presented in science textbooks for the 14-18 years age groups, the number of elements and details about their nature and interrelations is reduced. Interestingly, although the complexity of the content is reduced, compared to the higher scientific levels, diagrams for the 14-18 year levels still include several ambiguities. Figure 1.1 demonstrates this.

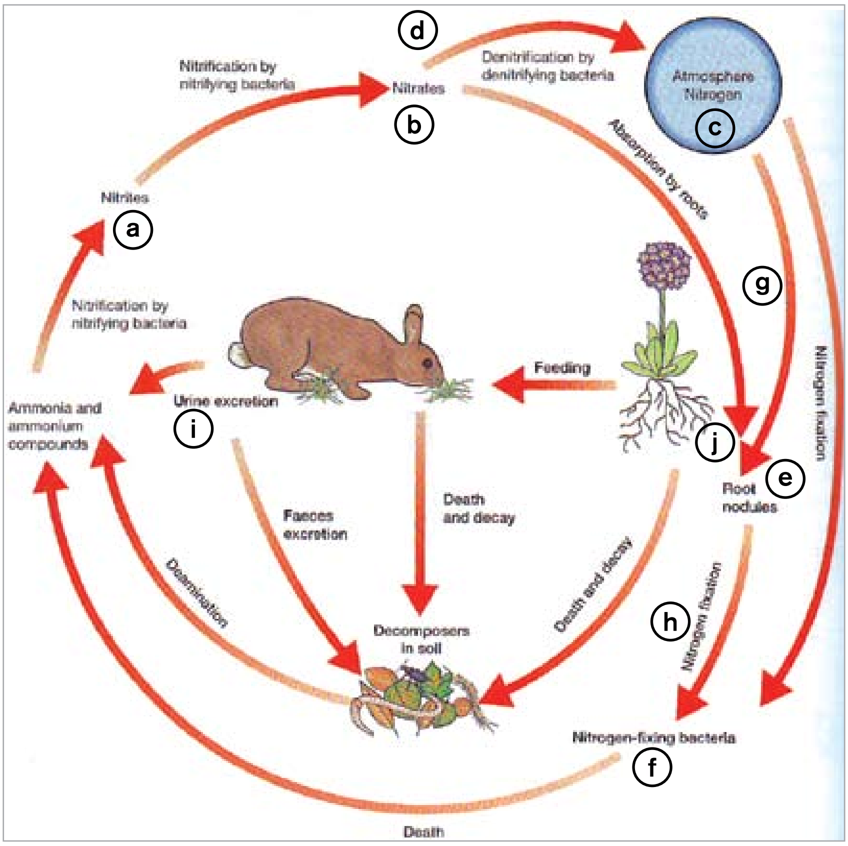


Figure 1.1: Nitrogen Cycle from Lea *et al* (2001: 212)

Looking across the nodes – for now defined as the words or pictures linked by arrows – we find a sequence which indicates a gradual transformation process through different states of matter: 'nitrites' [a], 'nitrates' [b], 'atmospheric nitrogen' [c]. These nodes are linked in a logical sequence by arrows with labels that indicate the process and the process agent *eg,* 'denitrification by denitrifying bacteria' [d]. The next step of the sequence breaks this logic, because 'root nodule' [e] is part of a plant, *ie,* an organism rather than a state of matter; and is followed by 'nitrogen-fixing bacteria' [f], which is another organism as well as process agent. This linking sequence creates confusion about the nature of biological elements that are linked in the nitrogen cycle.

Ambiguity is also created within the arrow labels because visually similar arrows represent different information: One arrow [g] is unlabelled, the next arrow indicates a process 'nitrogen fixation' [h], these two arrows carry different meanings than [d], which includes the process and the process agent. When a single graphic object, or group of graphic objects, may represent more than one meaning, it is polysemic (Bertin, 1983; 2000/01). The particular combination of implicit and explicit information types in figure 1.1 creates a confusing message about the nitrogen cycle: the nature of elements and their interrelations are ambiguous, as is the essential message of what actually circulates in the cycle. Similar ambiguities are reported in research investigating science textbooks with a wider focus; Stylianidou *et al* (2002) found several arrow meanings in depictions of 'energy', and other critical issues, such as imprecise positioning of labels in relation to other graphic objects, and confusion caused by the wording in text labels. Such ambiguity is concerning, as Stylianidou *et al* (2002) and Ametller & Pintó (2002) found that students may have problems understanding these parts of the visuals, in particular polysemic graphic objects.

Ambiguity reflects back on the effectiveness of an ecological cycle network diagram, when seen from an information design perspective. An ambiguous message suggests that the way in which the biological information types are categorised in the composition of graphic objects is ineffective. This raises questions about how ambiguities come to exist in the published diagrams. What potential theoretical complications might affect the effectiveness of a visual output? And further within design practice in educational publishing which features affect the rationale when transforming a manuscript and visual references into a published diagram? To investigate how the categorisation of information in a graphic composition may lead to ambiguous messages, the ecological cycle network diagrams are in this research enquiry analysed in relation to graphic syntax.

1.2.2 Information categorisation using graphic syntax

Information categorisation here refers to analysing a defined source content, selecting graphic objects and organising the effective composition. This activity requires the designer to consider the internal structure of a diagram, *ie,* graphic objects and their graphic relations (Engelhardt, 2002; 2007) [section 2.3, p. 32]. Such compositional principles, or rules, relate to graphic syntax and theories of whether a 'grammar' may be defined for visual language (*eg,* Twyman, 1979, 1982; Richards, 1984; Engelhardt, 2002, 2007) [section 2.3 p. 32]. The theories within this area discuss the choices available to a designer, and the subsequent implications between 'what is shown': the diagram, and 'what is meant': the intended message of the diagram (Engelhardt, 2002: 98) in this thesis defined as 'content proper' (Richards, 1984: 3/25). Knowledge about the potential implications of 'what is shown' in relation to 'what is meant' in turn provides the designer with knowledge about potential effective – and ineffective – graphic composition.

Underpinning the analysis of graphic syntax is a 'universal' principle of visual perception (*eg,* Bertin, 1983; Tufte, 1997; Card *et al,* 1999; Engelhardt, 2002). Derived from Gestalt theory (Koffka, 1935), this principle assumes certain perceptual skills to be present in human beings in general, thus enabling reading of certain visual patterns regardless of social and cultural local contexts. Accordingly a red arrow, for example, is analysed in terms of visual similarity or spatial relation to other arrows, rather than the cultural significance of including a red arrow in a diagram. Whilst focusing specifically on theories aligned with the 'universal' principle, this thesis acknowledges that design is an interactive communication process (Crilly *et al,* 2008), in which the reader simultaneously may interpret the cultural meaning of a red arrow [section 2.3.1 p. 32]. The 'universal' principle has enabled existing guidelines about graphic tactics when engaging with graphic syntax.

1.2.2.1 Graphic syntax of network diagrams

Engelhardt (2002) defines levels of graphic syntax through recursively decomposing a 'graphic representation' as a 'graphic object', which may be:

> …an elementary graphic object, or a composite graphic object, consisting of:
>
> - a graphic space that is occupied by it, and
> - a set of graphic objects, which are contained within that graphic space, and
> - a set of graphic relations in which these graphic objects are involved
>
> (Engelhardt, 2002: 14).

The graphic objects in an ecological cycle network diagram serve two syntactic roles: nodes and connectors (Engelhardt, 2002: 40). Their syntactic 'object-to-object relations' explain that some objects – nodes – are connected by other objects – arrows (2002: 40) [figure 1.2]. In the content proper context, 'what is meant' here is that the correlating biological or chemical elements are connected and connecting respectively. Nodes and connectors thereby create two fundamental categories of included information types.

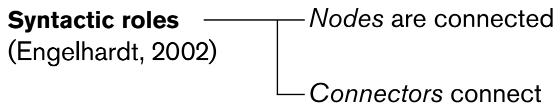


Figure 1.2: Basic syntactical roles of graphic objects in a network diagram.

1.2.2.2 Categories of information

The designer may create additional categories of information within or between the elements represented by nodes and connectors. This happens by visually associating graphic objects which represent related biological elements. Such visual association may happen both through graphic objects and through their graphic relations. For example, different information types represented in nodes may be further sub-categorised using pictorial objects to show organisms and text to represent matter. The elements in the text objects may again be sub-categorised by applying a container shape around some, *eg,* 'atmospheric nitrogen' [c] [figure 1.1, p. 6], or typographic attributes such as bold. The element represented by one node or connector may thereby simultaneously be included in several different information categories. Six graphic relations form the analytical focus of this thesis, here defined as graphic syntax aspects [section 4.3.2.1, p. 107].

1.2.2.3 Graphic syntax aspects and graphic tactics

The graphic syntax aspects analysed in this research enquiry enable identification of the information represented in a diagram and how it is categorized using 1) node and connector syntactic roles, 2) pictorial objects, 3) arrow types within connectors, 4) visual attributes, *eg*, shapes or colour, 5) typographic attributes, and 6) verbal syntax in text objects. The first four graphic syntax aspects are informed by Engelhardt (2002; 2007), typographic attributes by Richards (1984), whilst the analysis of verbal syntax is inspired by Stylianidou *et al* (2002) and expanded with more detail in this thesis.

The designer's selection and organisation of graphic objects and graphic relations to represent an information type and its interrelations is here referred to as graphic tactics [section 2.1.3.2, p. 29]. An ineffective graphic tactic may result in an ambiguous message about the content proper. In this research enquiry ineffective graphic tactics are identified through indicators of graphic ineffectiveness.

1.2.2.4 Indicators of graphic ineffectiveness

These theoretical measures are based on general critical issues in visuals for science textbooks – as found by Stylianidou *et al* (2002) – and developed in this research enquiry in relation to graphic syntax through a pilot visual content analysis [section 3.2.3, p. 76]. Four indicators of graphic ineffectiveness identify two sources of ineffective graphic tactics. Firstly, the relative spatial positioning of graphic objects may create ambiguity:

- Implicit nodes are demonstrated in figure 1.1 [p. 6] by an arrow meeting another arrow, rather than the node [j]. It is here unclear whether there is an implicit connected element.
- Imprecise nodes are graphic objects placed in close spatial proximity to two different graphic objects, *eg,* 'urine excretion' [i]; it is unclear whether it is a connected or connecting element.

Secondly, ambiguity may result from the number of different information types represented by visually similar nodes and connectors:

- Polysemy appears when visually similar nodes include different information types – seen within the arrows in figure 1.1 [p. 6]– or when the meaning is left for the reader to interpret, *eg,* the unlabelled arrow [g].
- Inconsistency is a measure applied in this research enquiry to analyse visual and typographic attributes, and verbal syntax, and detect the consistency with which these elements are applied. For example, if all the information types represented by a blue colour code belong to the same group.

These indicators of graphic ineffectiveness define the limitations in options for graphic tactics within each graphic syntax aspect, as defined within the focus of this research enquiry. These options for graphic tactics form the units of analysis in the visual content analysis and are presented as a coding scheme [chapter 4].

1.2.2.5 Visual content analysis coding scheme

The coding scheme developed as part of this research enquiry serves the practical function of documenting the units of analysis. This reveals the general potential theoretical complication involved when designing a network diagram. Practically, the coding scheme enables identification of information categorisation and ineffective graphic tactics in existing visual output [chapter 5]. These identified ineffective graphic tactics are summarised in tabular format, contributing a tool to practitioners for reviewing their visual output [table 5.1, p. 203].

The coding scheme serves the additional conceptual function of representing the design problem investigated in this research enquiry (Cross, 2000; Dorst and Cross, 2001), *ie,* the visual composition challenge facing a designer when designing an ecological cycle network diagram [section 4.4, p. 115]. In this definition, the ineffective graphic tactics represent internal constraints (Lawson, 2006). Within this research enquiry, the conceptual function of the coding scheme positions the focus of the *first research strand* in relation to the *second research strand*. This enables identification of the features in educational publishing which may affect the design decisions.

1.3 Professional practice context

This section introduces the *second research strand* and educational publishing. Here the visual output is traced through the professional practice context, to identify the design processes that generate ecological cycle network diagrams. This analysis is based on defining information transformation in educational publishing as a design situation.

1.3.1 Educational publishing

When seen in relation to design practice, the educational publishing design process is a simultaneous creative and management process (Evans *et al*, 1987; Puphaiboon, 2005). Several core participants – editors, authors, designers, illustrators – may here be formally, or informally, involved in an organic network of decision-making (Rowe, 1987). Of interest here is the direct relation between this type of design practice and the respective national curriculum; affecting decisions about the biological content included, and in some cases also which type of diagram to include in the first place (Edexcel, 2007). An additional reason for this research enquiry covering both the UK and Denmark, is to investigate how different levels of flexibility in the curriculum may affect the decision-making in the two countries [section 2.5.4, p. 59]. Several theoretical concepts are applied in this research enquiry to identify the features which may affect the rationale when transforming information into an ecological cycle network diagram.

1.3.2 Information transformation rationale

The professional practice context is in this research enquiry defined as part of a design situation (Dorst, 1997). A design situation constitutes a design problem – the information categorisation in an ecological cycle network diagram – and a situational context – the professional practice context. Figure 1.3 presents a simplified version of this relationship, which also illustrates the relations between the focus of each research strand.

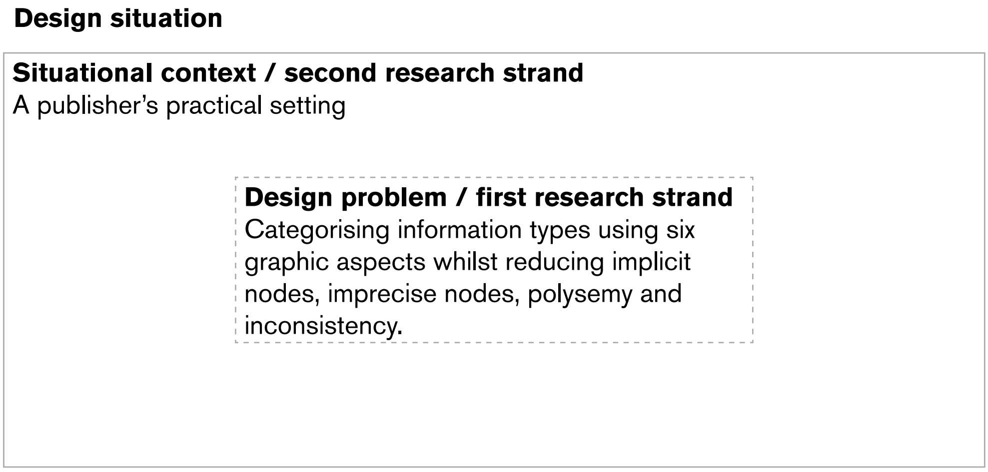


Figure 1.3: Information transformation situation/design situation (Dorst, 1997)

Where the *first research strand* of this enquiry identifies the internal constraints of the design problem, the *second research strand* reveals the external constraints which affect the rationale (Lawson, 2006), and how the participants navigate among them (Cross, 2000; Dorst and Cross, 2001). This results in two analytical perspectives of the design situation, hence for identifying the information transformation rationale in this research enquiry. Both analytical perspectives centre on 'choice points' (Schön, 2006) – points in the process at which decisions are made [section 2.4.3, p. 47].

Firstly, a cross–sectional, static, view of the design situation enables identification of the features, which the participants choose to attend to at each choice point, the variation in their approaches, and their reasoning. Secondly, a process oriented perspective identifies how the design problem is solved within the situational context, in a given time, *ie,* performing the design task (Dorst, 1997). To enable this second analytical perspective, the design problem is viewed as comprising a problem space and a solution space (Cross, 2000), including sub-spaces; the six graphic syntax aspects representing the sub-problems. To perform the design task, the designer pairs the sub-problems with potential sub-solutions (Cross, 2002). As such, the problem and solution spaces co-evolve towards the final solution (Cross, 2000; Dorst and Cross, 2001); as does the implications of the decisions. This continuous evolution of implications means that the design problem exists as an organic, 'ill-defined' entity (Rowe, 1987), which is being defined or set, as the task progresses (Schön, 2006; Cross, 2000; Dorst and Cross, 2001). Information transformation thereby represents a problem setting process (Schön, 2006). Tracing the visual output through this process enables analysis of the interrelations between decisions in the professional practice context and the existence of ambiguities in the published diagrams. In this research enquiry, this analysis is facilitated by integrating the research findings from the two research strands.

1.3.3 Integrating research findings

The research findings emerging from this research enquiry are integrated through identifying the models of design activities (Dumas and Mintzberg, 1991) applied in current practice. Analysing interrelations between the models of design activity, potential theoretical complication, and the identified ineffective graphic tactics, in turn reveals any links between the decision-making and occurrences of ambiguity in the visual output. Thereby this analysis uncovers plausible implications of the decision-making in current practice in relation to ambiguities in existing visual output. Based on the integrated findings it is possible to suggest a set of recommendations for an alternative information transformation rationale. These recommendations build on suggestions from the interviewed participants, the integrated research findings, and information design theory.

Practically, the integration of research findings is facilitated by basing the interview questions on the analysed graphic syntax aspects and findings from the pilot visual content analysis. Thereby this thesis reveals important intrinsic aspects of design practice in educational publishing. This outcome complements existing research on the educational publishing design process (Puphaiboon, 2005; Evans *et al*, 1987) by highlighting how the delegation of responsibility in the process – including acknowledged and unacknowledged contributions (Gorb and Dumas, 1987; Dumas and Mintzberg, 1991) – may affect the information transformation rationale. This combined focus – on visual output and the production context – yields an argument for increasing the precision in the design of the diagrams, by implementing a coherent overview of information design principles at significant choice points.

1.4 Research questions, aims, and objectives

This research enquiry is guided by questioning how ambiguities come to exist in ecological cycle network diagrams in science textbooks for the 14-18 years age groups. What potential theoretical complications might affect the effectiveness of a visual output? And which features within design practice in educational publishing affect the rationale when transforming a manuscript and visual references into a published diagram?

1.4.1 Aims

Based on these research questions, the aims of this thesis are to identify:

- How information in existing ecological cycle network diagrams is categorised using graphic syntax.

- How information is transformed into ecological cycle network diagrams in science textbooks.

- How design decisions may affect the graphic composition.

- How an alternative information transformation rationale may be defined, based on the research findings, and graphic syntax theory.

1.4.1.2 Objectives

The aims in turn yields the following objectives:

- Collection of ecological cycles network diagrams from Danish and UK science textbooks for the 14-18 years age groups.

- Review of literature to identify appropriate theoretical framework for analysing graphic syntax.

- Analysis of diagram collection to identify information categorisation using graphic syntax.

- Based on analysis findings, to formulate interview questions for identifying approaches to transforming information into ecological cycle network diagrams.

- Examine professional practice, by identifying main participants in the educational publishing process and investigate their role, methods, processes and evaluation frameworks in relation to the defined interview questions.

- Examining the relationship between findings relating to the theoretical context and the professional practical context of an ecological cycle network diagram, to identify themes for systematic underpinning an alternative information transformation rationale.

1.5 Methodology

This research enquiry is defined as practice-led, as a result of a practicing designer investigating a design problem in its professional context. A practice-led approach will demonstrate how theory may inform practice, and vice-versa, both aiming at enhancing future design practice and theory.

1.5.1 Multiple methods

The research aims and objectives are met by applying multiple research methods: visual content analysis (Rose, 2007) of 209 ecological cycle network diagrams in the *first research strand*, and semi-structured interviews (Robson, 2002) with 19 editors, authors, designers, and illustrators at six publishers (UK and Denmark) in the *second research strand*. The interview data set is analysed using phenomenographic data analysis method (Green and Bowden, 2005). Phenomenography is an empirical research method which, in the context of this research enquiry, enables identification of variation and similarities in approaches to design practice across a field (Daly *et al,* 2008). Guiding the combination of these methods, and the research enquiry, is a practice-led approach to research.

1.5.2 Practice-led research

Frayling describes three different approaches to research in an art and design context (1993: 5, italics added): 'Research *into* practice' – studying the practice of other artists or designers, 'research *through* practice' – the practice serving a purpose to meet the research aims, 'research *for* practice' – practical aims prioritized above research aims. The former two approaches represent cornerstones in the academic field of design practitioners investigating design practice. The terms *practice-led* and *practice-based* research are often used synonymously to describe this research activity. However, Woolley (2000a, here from Dixon, 2001: 3.17) defines a 'practice-led' approach as 'research initiated by practice for the purposes of enriching or modifying aspects of a particular discipline or profession'. Practice-led hence reflecting Frayling's 'research *into* practice'. 'Practice-based' research, on the other hand, is by Evans (2000) described as applying 'the working practices intrinsic to the studio or workshop as a method in the structured process of research and in some cases perhaps as the methodology' (Evans, 2000, here from Dixon 2001:3.17); hence reflecting Frayling's 'research *through* practice'.

This research enquiry is practice-led due, firstly, to the initial starting point being a practical design problem, that of ambiguity in network diagrams; secondly, by being initiated and conducted by a practicing designer[1]; thirdly, by investigating the professional practice through which existing diagrams are generated, rather than using design practice to develop a practical outcome or resolutions. Woolley further broadens the definition of practice to include 'the design of organisations, process, system, structure, group/team, *etc.*' (Woolley, 2000b), and presents a general vision for practice-led research:

> 'For a research investigation that simultaneously reflects on and enhances practice, together with analysis of the difficulties to be overcome, before "making change" will effectively "change making."'

By closely linking the identified graphic tactics with related design decisions, this thesis contributes to analysis of both theoretical and practical difficulties, which need to be addressed before future practice is enhanced.

1.5.2.1 Practice-led contributions to research

A defining feature of this research enquiry is its nature as a bridge between theory and professional practice. The foundation for this bridge is laid by visual analytical frameworks originating from design practitioners (Richards, 1984; Gillieson, 2008). This thesis contributes by practically demonstrating how current practitioners may apply such information design theory (Richards, 1984; Engelhardt, 2002), and descriptive models of the design process (Dumas and Mintzberg, 1991; Cross, 2000; Dorst and Cross, 2001; Lawson, 2006; Schön, 2006; Crilly, 2005) to review current practice, and utilise the findings to improve future practice. The interviews conducted have already contributed towards this aim. The direct contact with participants in educational design practice has created some local interest in the subject, as expressed by the interviewees [section 6.7.4, p. 300]; as well

1 My professional background lies within graphic design such as corporate identity, exhibition design, and design education, *ie,* excluding practical experience in educational publishing.

as yielding suggestions from the interviewees for improving future practice. These suggestions form the basis for the recommendations put forward by this thesis; which thereby provides further evidence and development of the participants' suggestions, rather than prescribing 'best practice'.

Where knowledge and application of theory seeks to enhance future professional practice, feedback may also run in the opposite direction (Gillieson, 2008). Here current practice may inform the development of future theory. The practice-led approach here provides essential contextual knowledge about the practical features within the professional practice setting, which influence the diagram development.

An overview of the thesis structure is provided by figure 1.4. This diagram is repeated at the beginning of each chapter throughout the thesis, to aide the navigation of the argument.

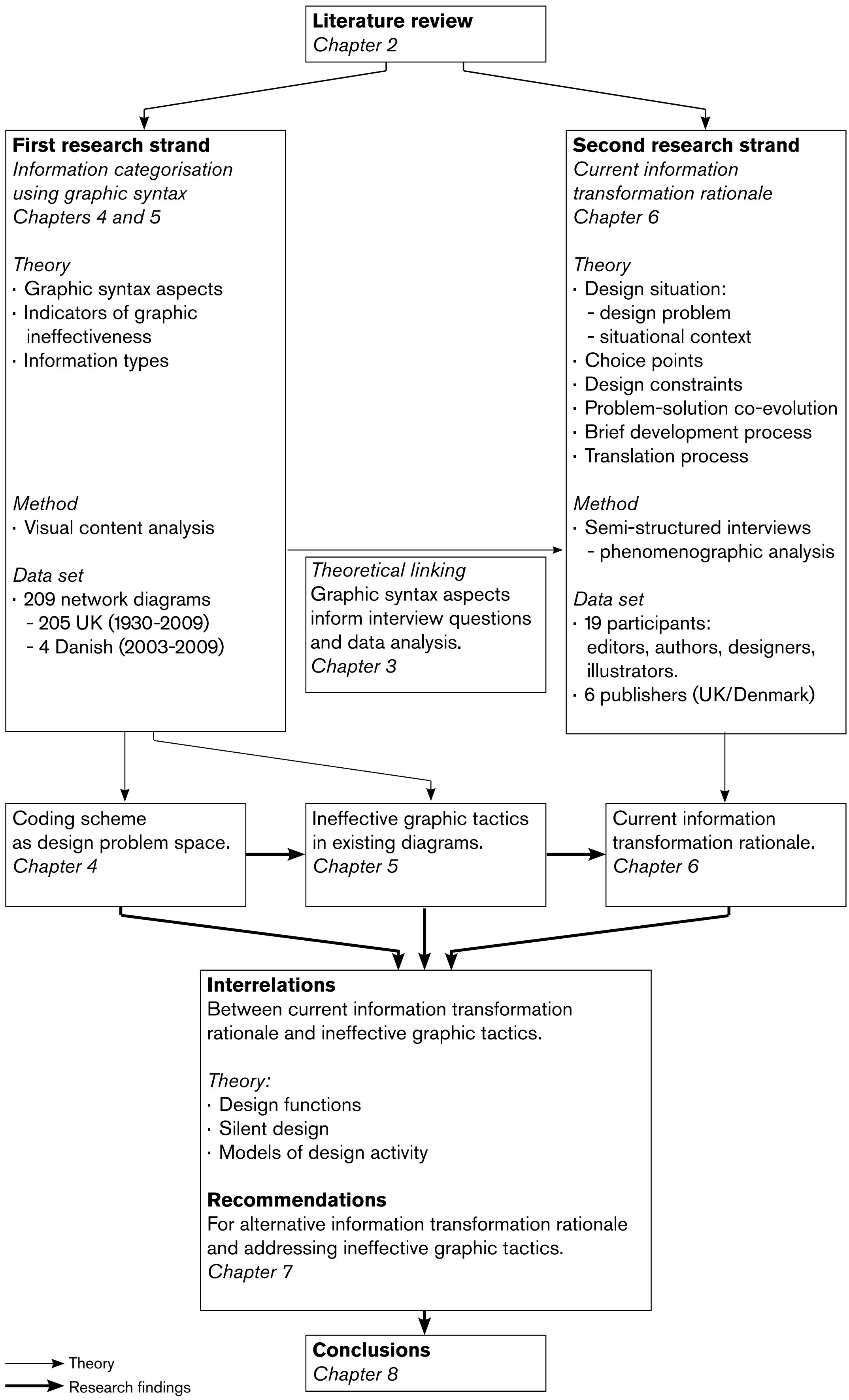


Figure 1.4: Conceptual framework of thesis

Summary

This thesis, and the practice-led research enquiry on which it is based, were here introduced as a 'meta-reflection-on-practice', in which a practitioner stands back and observes an information design problem – an ecological cycle network diagram – in its professional practice context, namely educational publishing.

Information design was described as an interactive communication process and visual outputs focused on effectiveness of communication.

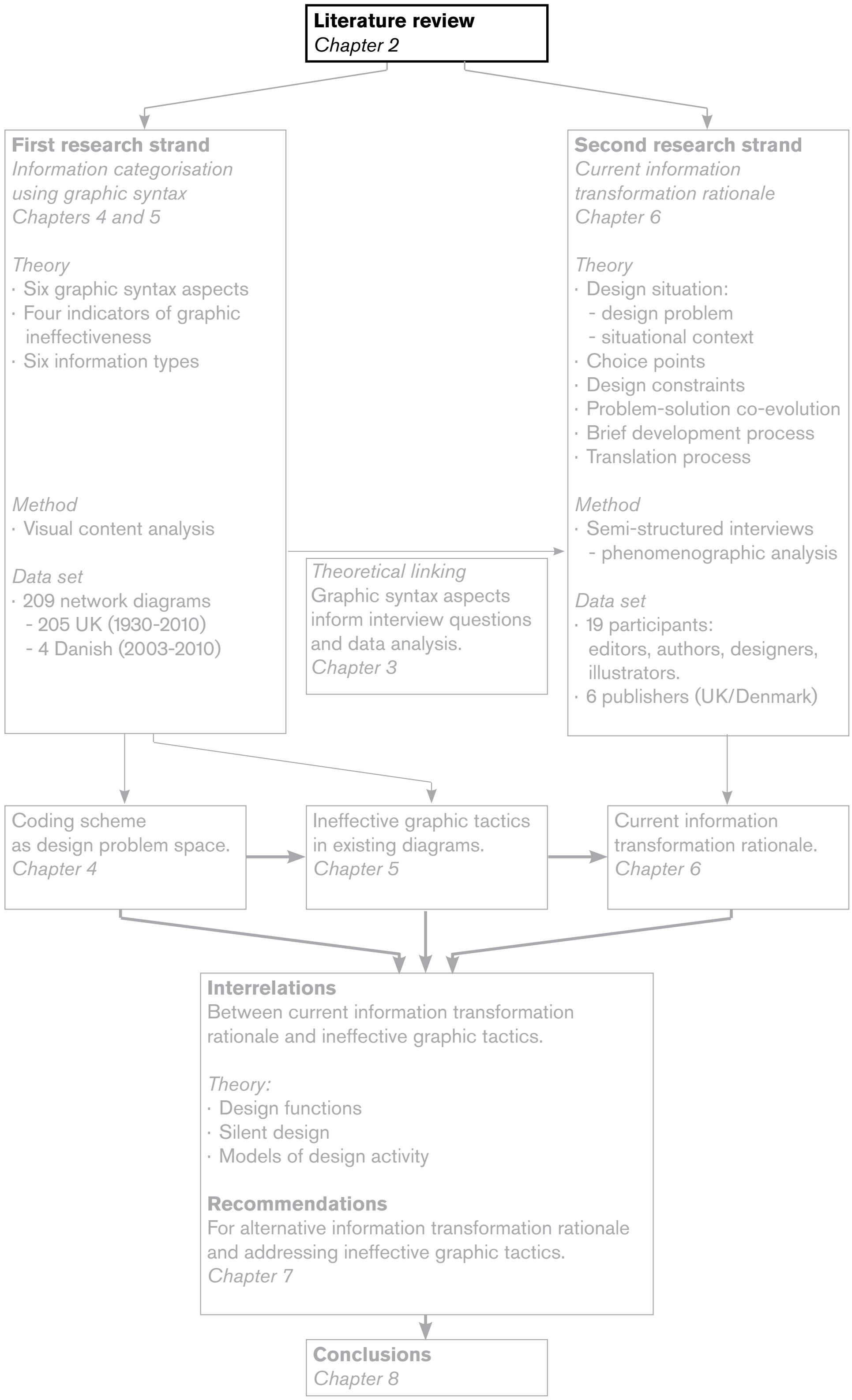
The *first research strand* was introduced as focused on visual content analysis of the visual output using graphic syntax theory; enabling identification of ineffective graphic tactics.

Ineffective graphic tactics were defined as instances of graphic objects in graphic relations which may lead to ambiguity about the cycle subject. Four indicators of graphic ineffectiveness, were presented: implicit nodes, imprecise nodes, polysemy and inconsistency. The ecological cycle network diagram was defined as the design problem space

The *second research strand* was introduced as focused on tracing the visual output through the educational publishing design process – using semi-structured interviews – to identify the rationale for transforming information into an ecological cycle network diagram.

The publishing context was defined as a design situation comprising a situational context and design problem, enabling integration with research findings from the professional practice context, to investigate how design decisions may affect the occurrence of ambiguity.

2 Literature review


Literature review
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Information categorisation using graphic syntax
Chapters 4 and 5
Theory
· Six graphic syntax aspects
· Four indicators of graphic ineffectiveness
· Six information types
Method
· Visual content analysis
Data set
· 209 network diagrams
- 205 UK (1930-2010)
- 4 Danish (2003-2010)
Second research strand
Current information transformation rationale
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Theory
· Design situation:
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- situational context
· Choice points
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· Brief development process
· Translation process
Method
· Semi-structured interviews
- phenomenographic analysis
Data set
· 19 participants:
editors, authors, designers, illustrators.
· 6 publishers (UK/Denmark)
Theoretical linking
Graphic syntax aspects inform interview questions and data analysis.
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2 Literature review

2.1 Field of study: Information design

This section introduces the field of study in this research enquiry as information design practice and the academic study of practice. Information design is defined by its focus on effective communication. The information design process is here synonymous with information transformation, which entails decisions about the graphic strategy and graphic tactics.

2.1.1 Information design practice and the academic study of practice

The field studied in this research enquiry is information design. Information design practice produces a range of different visual outputs in electronic and printed media, such as diagrams, maps, screen interfaces, time tables, and medical information leaflets (Baer, 2010; Few, 2006; Jacobson, 2000). Some types of visual outputs, which may be described as an example of information design, have existed throughout history; exemplified by a lunar calendar etched on animal bones (c38,000BC) (Horn, 1999: 23), the physician John Snow's cholera maps of London (1854) (Wainer, 2005: 135) or civil engineer Minard's visualisation of Napoleons march (1869) (Tufte, 1997: 41). Many such visual outputs derive from scientists needing an accurate visual description of scientific knowledge. In an increasingly complex world, the need for accurate visual description has grown within other areas *eg,* military and technological training, and with it has grown the field of information design practice (Stiff, 2000/01).

In contrast to the above examples of visual output, the academic study of information design practice, and its visual output, is relatively young. Stiff (2000/01) pins the late 1970s as the dawn of this academic field. Stiff – and Horn (1999) – attributes the definition of this design practice and the academic study as information design, to a period of activity which saw light at the first conference on information design[1] in 1978 and the subsequent publication of the conference papers (Easterby and Zwaga, 1984). This period also yielded the inaugural issue of the *Information Design Journal* (IDJ) in

1 *NATO Conference on Visual Presentation of Information*

1979, described as a meeting place for researchers, designers, technologists, social scientists, psychologists and educationalists. This multidisciplinarity is present in the field today. Although knowledge has deepened with the growing academic field, recent theoretical frameworks (*eg*, Gillieson, 2008) draw on references from a range of subject areas in addition to information design, such as linguistics, psychology, literary criticism, and art history. Through these multidisciplinary sources, information design theory enables the defining, planning, and composing of effective communication.

2.1.2 Defining, planning, and composing effective communication

Information design practice is often described as parallel to, or included in, graphic design, communication design, or document design – the design of complex 'texts' (Schriver, 1997). For example, Westendorp and Van der Waarde (2000/01: 1) describe typography as a 'traditional information design area', whilst Buchanan (1992: 9) includes typography, advertising, book, magazine production, and scientific illustration as graphic design. The overlaps are grounded in the similar visual outputs each field engages with, for example, book design – and in a shared graphic palette – format, size, grid, basic graphic objects (shapes, text and pictures), typographic styling through fonts, font size, font weight, spacing (kerning, leading, tracking, indents), and colours (CMYK, RGB).

Buchanan (2001: 201) describes how communication design evolved through broadening the graphic design field; today encompassing information design, graphic design, and document design (Schriver, 1997). Information design in turn encompasses document design through similar aims and outputs (Schriver, 1997: 6-7). In this thesis the boundary between information design and document design is drawn, by focusing on the practice of organising graphic objects and graphic relations within an individual diagram, rather than a diagram in relation to other page elements. Richards (1984: 1/1) contrasts information design and graphic design by the former's intention to 'describe, explain or instruct'; whereas graphic design is 'characterised by the intention to amuse, delight, persuade, invigorate, provoke or otherwise stimulate'. Richards' view is reflected by Horn (1999) and referenced by Engelhardt (2002: 2). However, the intentions with information design appear blurred in today's landscape. Reynolds (2002/3: 186), for example, describes how '…the graphic design approach still dominates information design today, text and writings still focus on making information look good'. Similarly, a diagram, if seen as a visual argument (Tufte, 1997; Buchanan, 1992; Kostelnick, 1995; Buchanan, 2000), may be applied to persuade an audience of a certain position, *eg,* as 'the scientific bit' in a shampoo advert.

If defining information design based on its overall intention is insufficient for this enquiry, Kinross' (1984) suggestions appear more appropriate. He distinguishes information design as concerned with the effectiveness of graphic and typographic communications (1984: 10). In this thesis, information design is defined by a focus on effective composition of graphic objects. Effectiveness is here seen in relation to indicators of graphic ineffectiveness: implicit nodes, imprecise nodes, polysemy and inconsistency; in turn aiming at reducing the content proper ambiguity [section 4.3.2.2, p. 110].

Information design practice may be further specified by the designer's level of engagement with the source information, rather than simply organising a 'given' material in a visual composition. The International Institute for Information Design (IIID) defines information design as 'the defining, planning, and shaping of the contents of a message and the environments in which it is presented, with the intention to satisfy the information needs of the intended recipients' (IIID, 2010). Based on this, information design practice is in this thesis defined as the defining and planning of source information, and effective composition of graphic objects in relation to precision in communication. Information design practice is here synonymous with information transformation.

2.1.3 Information design practice as information transformation

This thesis is concerned with the rationale for transforming information into ecological cycle network diagrams. Rationale relates to the designer's reasoning when defining, planning, and composing a visual output. In the science textbook context this relates to transforming mainly verbal information – manuscripts, but also visual references – into visual language. Verbal and visual language is defined in section 2.3.1 below. The essence of transformation in this thesis is similar to translation, a term favoured by Engelhardt (2002: 4) and defined by (Pearsall, 2002) as 'to express the sense of (words or text) in another language'. However, transformation in this thesis differs from textual translation, by addressing both visual and verbal modes, rather than translation, which refers solely to the verbal mode. Bertin (1983: 4) applies 'transcription' to describe transformation activity, indicating close correlation between the verbal and visual information. This seems appropriate in his cartographic context of 'transcribing' empirical data into precise data visualisation. However, he also applies the term 'transformation' to describe the re-arrangement of graphic objects within a 'graphic' following the initial plotting (1983: 269). In the context of this thesis information transformation relates to a broader set of activities when completing the design task: both the definition and planning of source information, and the composition through analysing the defined source content, selecting graphic objects and organising the effective composition. Translation is in this thesis applied to discuss an information transformation sub-process [section 2.5.2.1, p. 56]: that of translating an artwork brief into a network diagram.

Given the focus of defining, planning, and composing, the information designer may be described as an information transformer. This term originates from Otto Neurath's process for ISOTYPE (Neurath and Kinross, 2008). Macdonald-Ross and Waller (2000: 178) describe the information transformer as a 'skilled professional communicator who mediates between the expert and the reader'. They argue that design in this role helps the construction of the message, rather than simply providing external decoration. This role is similar to Richards' description of an information designer (2000/01: 89). In this thesis, information categorisation refers to the sub-activity of analysing the defined source content, selecting graphic objects and organising the effective composition; a tactical level of information transformation.

2.1.3.1 Information transformation strategy and tactics

To enable detailed analysis of information transformation it is here defined as comprising a strategic and tactical level in relation to decision-making:

- **Information transformation strategy** relates to defining and planning the source information, for example, deciding to include visuals in the first place, and defining the biological content.

- **Information transformation tactics** relate to analysing the defined source content and deciding the diagram type.
  Information transformation tactics are here synonymous with information categorisation. This is further defined – in a recursive application of strategy and tactics – as comprising graphic strategy and graphic tactics.

2.1.3.2 Graphic strategy and tactics

This recursive definition of levels of decision-making within information categorisation increases the precision when identifying the parts of a visual output which may lead to ambiguity. This later enables recommendation of alternative graphic strategies as well as graphic tactics, as part of this thesis:

- **Graphic strategy** is synonymous with **information transformation tactics**, referring to analysing the defined source content and deciding the diagram type.
- **Graphic tactics** refer to a selection and organisation of graphic objects and graphic relations within a graphic syntax aspect to represent an information type and its interrelations.
  This recursive definition is summarised in figure 2.1. Later, in connection with the *second research strand*, the graphic strategy and tactics are defined as representing the overall- and sub-problem space of the design problem [section 6.2.2, p. 225].

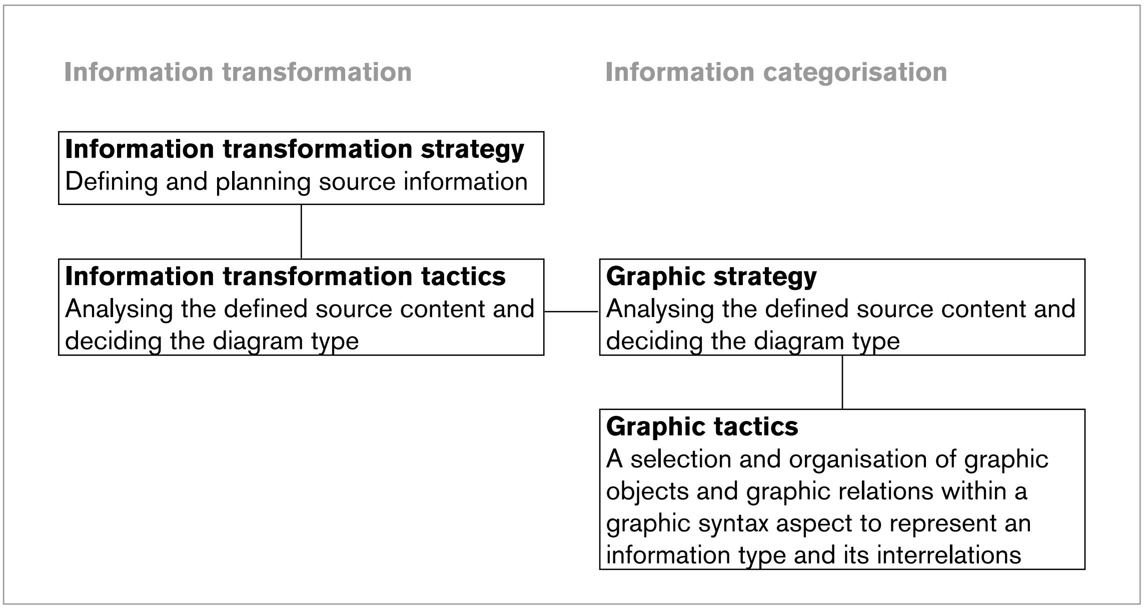


Figure 2.1 Recursive definition of strategy and tactics.

2.2 Ecological cycle network diagrams in science textbooks

A network diagram has a fundamental effectiveness for visually explaining ecological cycles. This forms part of the basic information transformation rationale, and highlights the need for precision to ensure the integrity of the visual output.

2.2.1 Effective composition and integrity of visual output

A network diagram is a ubiquitous visual output for visually explaining ecological cycles; often applied to explain the intricacies of flows, and microscopic or abstract processes (Schriver, 1997; Winn, 1989). Research within instructional science reveals part of the underlying, general, rationale for including different visual modes, such as diagrams, in textbooks (*eg*, Simon and Larkin, 1987; Chandler and Sweller, 1988; Tversky, 2000). Useful reviews of this area exist in Goldsmith (1984), Levin *et al* (1987) and Schriver (1997). Referencing such studies, Winn (1987: 160) lists some positive physiological and cognitive effects from using diagrams to explain subjects such as ecological cycles, which are harder to describe in linear verbal prose. These positive effects include the diagram's ability to make spatial relationships meaningful, *ie,* pattern recognition based on Gestalt principles, and simultaneous processing of information. Based on this existing research, the underlying assumption in this thesis is that a network diagram has a fundamental effectiveness for visually explaining relationships and flows in ecological cycles. This in turn provides a general purpose for the visual output, as part of the information transformation rationale [section 6.5.1.1, p. 237].

The popularity of network diagrams is partly due to the simplicity in using arrows, text, and possible pictorial objects to show complex systems. However, the simple combination of graphic objects increases the demand for precision when representing information using graphic objects and their graphic relations. An ecological cycle network diagram requires particular attention to the level of complication posed by simultaneously explaining the role of biological concepts and their mutual interrelations, using nodes and connectors. Ineffective information categorisation – using graphic objects and their graphic relations – may create ambiguity as demonstrated by figure 1.1 [p. 6]. This issue is also highlighted by several authors (Stylianidou *et al*, 2002; Tufte, 2006; Bertin, 1983).

An ineffective composition relates to the diagram's reliability and integrity. Tufte (1997: 10) notes that 'since such displays [visual explanations] are often used to reach conclusions and make decisions, there is a special concern with the integrity of the content and the design'. Doblin (1980: 104) compares the integrity of a visual to a 'well-operating machine', based on the 'right assortment of parts which must be properly assembled'. He argues that, for example, an 'out-of-perspective drawing' or a 'grammatically wrong statement' may be inefficient in transmitting information (1980: 104) or even misinform (1980: 107). In the context of this enquiry, the reliability and integrity of the diagram is a crucial element in the pupils' learning. This positions the diagram designer in an essential role and with responsibility; highlighting the need for precision when planning and defining the diagram content and composition. This precision may be informed by theoretical models of graphic syntax.

2.3 Analysing graphic syntax: a visual language

The theoretical framework for analysing ecological cycle network diagrams – in the *first research strand* of this enquiry – centres on graphic syntax theory. Such theory derives from studying visual language and has a theoretical foundation of Gestalt theory and semiotics. Graphic syntax theory here enables analysis of the meaning created by graphic objects and their graphic relations in ecological cycle network diagrams.

2.3.1 A visual and verbal language analogy

Twyman (1982: 7) defines visual graphic language to include verbal, pictorial, and schematic modes. The study of such visual language opens up the possibility for comparison between visual and verbal language and questioning, whether a visual 'grammar' may be defined based on the internal structure and interrelations between graphic objects (Kinross, 1986). A visual 'grammar' here relates to the existence of a 'universal' principle for perception in which readers potentially interpret the same meaning from a graphic composition, regardless of cultural background and local context (Bertin, 1983; 2000/01; Tufte, 1997; Engelhardt, 2002; Gillieson, 2008). Graphic syntax theory enables the designer to enhance the precision and effectiveness of a message, whilst still acknowledging information design as an interactive communication process, affected by the reader's personal experience and background. Gestalt theory is the foundation for this 'universal' principle.

2.3.1.1 Gestalt theory and visual perception

Gestalt theory informs graphic syntax knowledge about the nature of the human brain to organise visual stimuli when processing visuals. Gestalt psychology's founders, Max Wertheimer, Wolfgang Köhler, and Kurt Koffka focused on studying the internal processes of human cognition, thereby breaking away from their contemporaries – the behaviourists studying external observable responses only. The Gestalt theorists argued that the brain 'organises' an image to perceive the inputs; and identified several 'laws' guiding this internal 'organisation'.

The basic gestalt principle, Wertheimer's *law of prägnanz* suggests that the brain favours the 'simplest and best' interpretation when organising an image (Koffka, 1935: 110). The basic activity for the brain to arrive at the 'simplest and best' is to extract objects from the background and distinguishing between figure and ground relations [Figure 2.2].

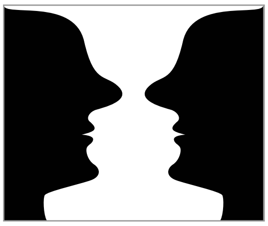
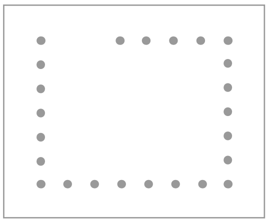


Figure 2.2: Figure and ground relation

The figure thus 'depends for its characteristics upon the ground on which it appears. The ground…determines the figure.' (Koffka, 1935/50: 184). An example is the letters of typeset text in this thesis, in which typeset 'figures' stand out from a white 'ground'. The brain follows four principles when organising figures:

Closure (Koffka, 1935: 150)

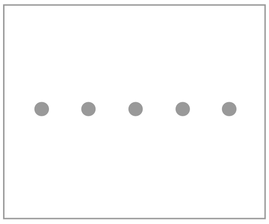
A figure may be perceived as 'whole' *ie,* completed in the mind, even if visually incomplete [Figure 2.3].



Figures 2.3: Gestalt principle: closure.

Good continuation (Koffka, 1935: 153)

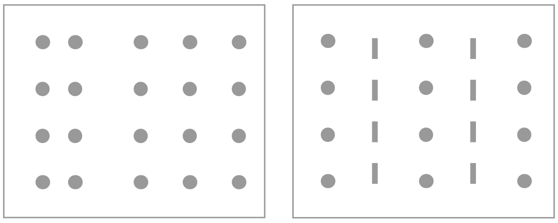
Figures forming a visual line are perceived as continuous, even if fragmented or interrupted by other figures [Figure 2.4].



Figures 2.4: Gestalt principle: good continuation.

Proximity and similarity (equality) (Koffka, 1935: 164)

Figures may be perceived as associated through similar shape or close spatial proximity, or disassociated through dissimilar shape and spatial distance [Figures 2.5-2.6].



Figures 2.5 and 2.6: Gestalt principles: proximity and similarity.

Figure strengths

The orientation of a figure, relative size, surroundings, and shape, affect the brain's distinction of figure and ground elements. Strong figures are less affected by their surrounding and tend to become the figure. Figure strength is affected by the following five aspects:

- *Orientation* (Koffka, 1935: 190): a figure's orientation affects the quality of its shape, relative to the frame.
- *Relative sizes* (Koffka, 1935: 191): perception of a figure is affected by the size of surrounding elements.
- *Enclosing/enclosed area* (Koffka, 1935: 192): if a figure is enclosed by another, the enclosing figure is perceived as the 'ground'.
- *Internal articulation* (Koffka, 1935: 193): higher contrast between figure and ground makes a figure 'stand out', thus better articulated.
- *Simplicity and symmetry* (Koffka, 1935: 195): relates to the *law of prägnanz;* The brain perceives a simpler and symmetrical figure more easily.

A popular summary of gestalt laws is that 'the whole is greater than the sum of its parts' (Groome, 2004). This happens because the 'whole' takes into account the relationships between the parts, based on the viewer's personal experience. In graphic syntax theory, this means that meaning is made, not just from individual graphic objects, but also from their graphic relations (Engelhardt, 2002). Although the 'law' terminology suggests a prescriptive rule set, Gestalt principles – in design contexts – constitute a general set of guidelines, rather than rules, as pointed out by Schriver (1997). In addition to Gestalt theory, graphic syntax knowledge builds on semiotic theory.

2.3.1.2 Pragmatic semiotics

Semiotic theory informs graphic syntax knowledge about 'what is meant' with 'what is shown' (Engelhardt, 2002: 97). A particular strand of semiotics, based on Morris (1938), runs directly or indirectly through the analytical models for graphic syntax reviewed here. Morris' framework (1938) is particularly applicable for graphic syntax theory due to its pragmatic nature and definition of three levels of reading. These three levels of reading, when interpreting graphic objects and their graphic relations, are:

- *Syntax* – how graphic objects and their graphic relations form meaningful and recognisable patterns as single or groups of images.
- *Semantic* – the relationship between 'what is shown' and 'what is meant' by the visual.
- *Pragmatic* – how the reader's social, cultural and local context affects the interpretation of the diagram.

Goldsmith (1980/1984) provides a direct link between Morris' framework and the graphic syntax theory models relevant for this thesis. She writes in the context of illustrations in adult learning material, and centres her model directly on Morris' three levels of analysis (Goldsmith, 1980: 204). Through this Goldsmith provided the platform for further developing analytical models for information design.

2.3.2 Models for analysing graphic syntax

This section presents theoretical frameworks reviewed for the *first research strand,* and the reasoning for selecting Engelhardt (2002) for application. In *Comprehensibility of illustration – an analytical model,* Evelyn Goldsmith

(1980) adopts Morris' (1938) terminology and defines the three levels of comprehension within the visual context (1980: 204). Goldsmith's 'text parallel' category of analysis focuses on the relation between image and text when the image is intended as a translation of the text. However, the scope is limited to illustrations. This model is thereby insufficient for a detailed study of network diagrams. Goldsmith's work was developed further for a diagrammatic context by Clive Richards (1984).

Clive Richards' (1984; 2000; 2002) seminal PHD thesis *Diagrammatics* is a direct development of Twyman (1982) and Goldsmith (1980) focusing on diagram analysis. The defining feature of a diagram is for Richards its use in the 'picturing of relationships' (Richards 2000: 93). Richards' basic analysis unit is a 'significant element', a meaningful object synonymous with graphic objects in this thesis. Richards compares 'significant elements' to noun phrases (1984: 3/13). As such, some 'significant elements' may function similarly to grammatical nouns – both subjects and objects – others similarly to verbs. This part of Richards' model informs this thesis with details on the role of nodes and arrows within network diagrams [section 4.4.1, p. 115]. Richards' model [figure 2.7] includes two key and independent design variables and three fundamental organisational modes for interpreting and designing diagrams:

- *Modes of correspondence* – how the entire diagram corresponds to what it represents; ranging from literal, semi-literal, non-literal.
- *Modes of depiction* – an individual element's level of pictorial realism/ schematisation; ranging from figurative to non-figurative.
- *Modes of organisation*, which includes:
  Grouping – suggests that elements belong to the same category.
  Linking – suggests that elements are connected.
  Variation – suggests that elements have different values.

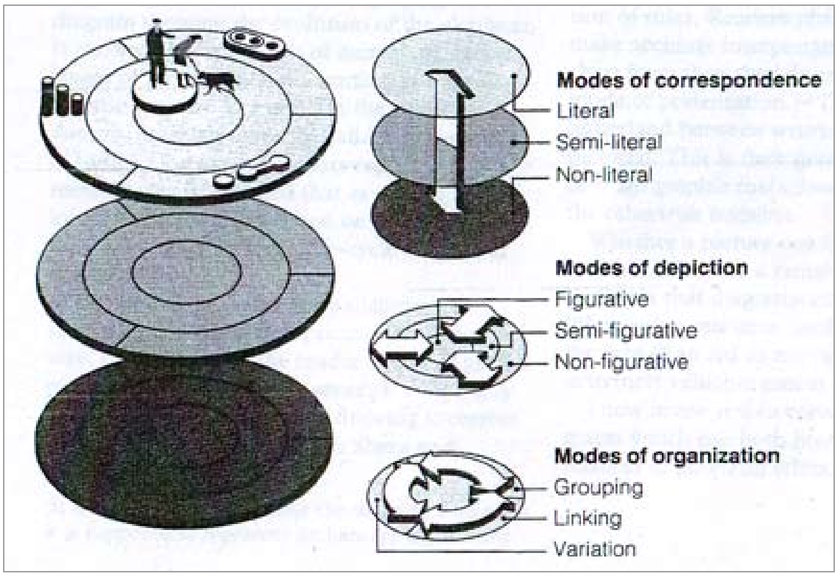


Figure 2.7: From Richards (2000/01: 97).

Richards' model explicitly omits analysis of text labels, unless these serve a noun or verb function (1984: 9/9, 9/23). This omission is one reason why Richards' model is not selected for the content analysis in this thesis. A second reason is that Engelhardt's (2002) later development of Richards' model offers expanded details to 'modes or organisation' – the syntax level. Instead Richards' model provides deeper detail for the underlying arguments about graphic syntax presented in chapter four and five.

Yuri Engelhardt's (2002; 2007) *The language of graphics* is a syntactic, comprehensive, and unifying framework. This framework adapts the three-mode structure of the previous models, particularly expanding on the syntactic level. Where Richards hesitates in pushing the similarities between the grammatical structures of verbal language and diagrams 'too' far (1984: 3/2), Engelhardt locates his framework much further within the linguistic basis. He cites Noam Chomsky's generative grammar as inspiration for this approach (2002: 22). Thus Engelhardt adds recursiveness to existing frameworks, enabling detailed decomposition of the syntactic relations between graphic objects[2].

2 Although Engelhardt includes a diagram of his recursiveness principle (2002: 14), regrettably he does not include a visual summary of the overall framework. This thesis presents a general overview, in connection with the content analysis coding scheme, in chapter 4, p. 106

At the syntactic level Engelhardt defines both 'object-to-object' relations and 'object-to-space' relations, and discusses how an object may serve several syntactic roles [section 4.3.1.1, p. 106]. Engelhardt further includes a 'broad inventory of syntactic principles' and provides a unifying terminology translation of synonymous terms used in visual analysis. Engelhardt includes text as an elementary graphic object – thus enabling labels as an analytical unit. This is a crucial addition for the application of his framework here, and a key area developed further in this research enquiry [section 4.4.2, p. 131]; leading to contributing detail about verbal syntax as a graphic syntax aspect [section 4.4.6, p. 150]. This thesis also contributes further details on typographic attributes as a graphic syntax aspect [section 4.4.5, p. 147]. Interestingly, Engelhardt's framework omits typographic detailing, where Richards includes typographic considerations of text included as noun objects, *eg,* upper and lower case (Richards, 1984: 9/22).

Katherine Gillieson's (2008) *Framework for graphic description in book design* integrates descriptive visual analysis models from a wide range of fields, and informs this thesis mainly as contextual reference. Gillieson's framework is informed by Richards (1984) as its foundation, reflects Engelhardt's (2002) unifying and recursive approach, and further draws on Goldsmith (1980/1984). Gillieson's framework enables a recursive analysis of book design elements and design strategies at a micro, macro and meta-level: single elements, groupings of single elements, and elements across the book. Simultaneously, the framework describes these elements in a 'rule' or 'context' category. 'Rules' is based on the 'universal' principles embraced in this research enquiry [section 2.3.1, p. 32] and on the practical conditions of book production. 'Context', meanwhile, relates to considerations of the broader contexts of the book, author, and reader. A major contribution of Gillieson's framework is the role of ratios between clusters of graphic objects on the page spread. This enables systematic analysis of proportions on a page – measured as 'granularity' and 'density'. The four theoretical frameworks are summarised in table 2.1, before discussing the nature of terminology within information design theory and practice.

	Scope	Analysis levels	Basic analysis unit
Goldsmith (1980; 1984)	Illustrations	· Syntactic · Semantic · Pragmatic	'Unity'
Richards (1984; 2000/01; 2002)	Diagrams	· Mode of correspondence · Mode of depiction · Mode of organisation	'Significant elements'
Engelhardt (2002; 2007)	Graphic representations including diagrams and illustrations	· Graphic syntax · Types of correspondence - Mode of expression	'Elementary graphic objects'
Gillieson (2008)	Page spreads across book, and individual elements	· Meta: elements across book · Macro: groups of basic component parts · Micro: basic component parts	'Basic component parts of page layout/micro features'

Table 2.1: Comparison of graphic syntax frameworks.

2.3.2.1 Terminology of theory and practice

Richards' inclusion and Engelhardt's exclusion of typographic considerations, may result from the first being a design-led approach (2000/01: 88), the latter deriving from computer science. This demonstrates the multidisciplinary nature of the academic information design field [section 2.1.1, p. 25]. Theoretical terminology often reflects the multi-sourced nature of information design theory, in addition to its nature as descriptive or generative, and the assumed audience level, *ie,* academic or practitioner. When tracing literature on the network diagram, for example, several terms for the same visual output were found: *eg,* network (Bertin, 1983), block diagram (Garland, 1968), or flow chart (Marcus, 1980). This issue was already highlighted in 1979 by Twyman (1979: 119).

Terminological discrepancy may filter through to the practical field, for example, in parallel descriptions of semiotic 'signs' and way finding 'signage' (Kinross, 1986: 194). Engelhardt (2002) addresses this through his *unifying terminology translation*. Unfortunately, a point of criticism from a design practice perspective is Engelhardt's own terminology (Gillieson, 2008). A practising designer may agree to naming their visual output as one of Engelhardt's overall types of representation, *eg,* map, chart or table. However, at a more detailed level – 'object-to-space' relations – Engelhardt refers, for example, to a ‘distorted metric space’, which is less likely to find acceptance in the practical field. On the other hand, Engelhardt’s use of ‘what is shown’ and ‘what is meant’ is a helpful colloquial approach to semiotic terminology; synonymous with Sausurre's use of ‘signifier’ and ‘signified’ (1969).

In addition to unifying approaches such as Engelhardt’s *terminology translations*, other examples include developing more accessible versions of academic theory. In an update, Bertin, for example, criticises the didactic approach of his own original work (2000/01: 5). Previously, others addressed this by disseminating more accessible descriptions of Bertin’s work (Mijksennar, 1997; Card *et al,* 1999). With this terminology issue in mind Engelhardt’s terminology is adopted here. However, section 3.3.3.2 [p. 86] discusses some practical research implications of adopting Engelhardt’s terminology in the visual content analysis, and later ‘translating’ it into accessible interview questions.

2.4 Analysing the design process

The theoretical framework for analysing the information transformation rationale – in the *second research strand* of this enquiry – centres on theoretical models from the academic study of design practice and methods. These enable identification and analysis of the design process, the nature of design problems, significant decision points in the information transformation process, and the features in a professional practice context which may affect the design decisions.

2.4.1 Models of the design process

The analytical framework applied in the *second research strand* draws on elements from several theoretical models; enabling analysis of different aspects of the information transformation rationale (Lawson, 2006; Schön, 2006; Crilly, 2005; Dorst and Cross, 2001; Cross, 2000; Dorst, 1997; Dumas and Mintzberg, 1991; Gorb and Dumas, 1987; Rowe, 1987). These models represent a 'second generation' of theoretical models (Rittel and Webber, 1973), which emerged after a crucial shift in understanding the nature of design problems, and the skills applied when solving them (Cross, 2000: 14).

Earlier - 'first generation' – models where based on viewing design problems as analogous to scientific problems. Seeing design problems as predictable, or 'well-defined' (Cross, 2000: 14), enabled delegation of sub-problems to individual specialists (Lawson, 2006). This resulted in theoretical models focused on developing rational and logical methods for a more systematic design process (Jones, 1992; Alexander, 1964; Cross, 1992). The second generation of models emerged through increasingly seeing design problems as 'ill-defined' (Simon, 1969) and less closely aligned with 'well-defined' scientific problems. These 'new methods' (Jones, 1992) include user and other expert involvement, embracing the different values of these participants; *ie,* analysing the design problem in its related context and describing the intrinsic parts of the design process and design problems.

Analysing and describing ill-defined problems may prove as challenging as solving them. Ill-defined problems have no set goal or prescribed procedures.

They are unpredictable, have flexible objectives, several possible answers, complex and multiple contexts, and unknown criteria and constraints (Simon, 1979; Rittel and Webber, 1973; Jones, 1992). The designer here engages with 'swampy' grounds, rather than a clear path through a terrain (Schön, 2006: 47). To solve an ill-defined problem thereby requires a flexible process which accommodates problem formulation and sub-formulation during the design process. In the theoretical context, the challenge of analysing and describing such process is met by the models applied here, through consolidating two contrasting views on design activity (Jones, 1992: 45-49): firstly, a 'creativity' view which perceives designers as 'black boxes' in which creativity happens unconsciously and internally only – like magic; secondly, a 'rational' view perceiving the designer as a 'glass box' performing a rational process which can be externalised and formally documented. By combining elements from both views, the models applied in this research enquiry enable analysis of information transformation as a process, which includes unpredictable features, tacit knowledge and problem setting as the preliminary design activity, when performing the design task.

2.4.2 Stages of the design process and problem setting

When prescribed by the early analytical models, the design process is a mainly linear process, in which both objective and subjective reasoning takes place (*eg,* Archer, 1964/1984). Archer considers objective observation, programming, and data collection as a preliminary analytical and inductive *reasoning phase*. This is followed by a *creative phase*, which includes analysis, synthesis, and development, involving deductive reasoning in subjective judgement. Objective reasoning is then re-applied in the final *executive phase,* for example, in the execution of working drawings and schedules. Archer describes these three stages as a 'creative sandwich': 'the bread of objective and systematic analysis may be thick or thin, but the creative act is always there in the middle' (1984: 6).

Ill-defined problems fit less easily within such linear path of reasoning and clearly separated stages. Models for describing ill-defined problems instead embrace the existence of distinct 'episodes' in a directional progression (Rowe, 1987: 34); each episode having a dominant activity and task. The crucial difference to older models is that subjective and objective reasoning takes place simultaneously at each stage. Jones (1992: 64), for example, suggests the process as starting with a *divergent stage* expanding and exploring the 'design situation' to enable wide search for a solution. This is followed by *transformation*, the generative and experimental creativity stage, and finally *convergence*, where the developed options are evaluated and the final solution chosen for production. The divergent nature of the first stage underscores the need for investigating a design problem within its situational context; in this thesis the ecological cycle network diagram in relation to educational publishing design practice.

In 'second generation' models – and their later developments – the design problem and solution are seen to exist in a parallel relationship. As such the preliminary, divergent, design activity aims at problem setting (Schön, 2006):

> 'Problem setting is the process in which, interactively, we name the things to which we will attend and frame the context in which we will attend to them.' (Schön, 2006: 40).

Problem setting thereby represents a stark contrast to the prescriptive theoretical models; here the preliminary analytical activities identified the solution and the specific route to physically manifest it. The nature of the problem setting process may be analysed, and explained, in more detail by looking at the difference between well-defined and ill-defined problem spaces.

2.4.2.1 Well-defined problem spaces

A well-defined problem space is often illustrated using a tree diagram (*eg*, Alexander, 1964) showing the sets of sub-problems from which the solution may be synthesised (Rowe, 1987: 51). Figure 2.8 shows a hierarchical decision tree diagram, in which nodes are knowledge states and links are courses of action (Rowe, 1987: 58). It illustrates how a well-defined design problem may be separated into different levels of sub-problems, each requiring individual decisions.

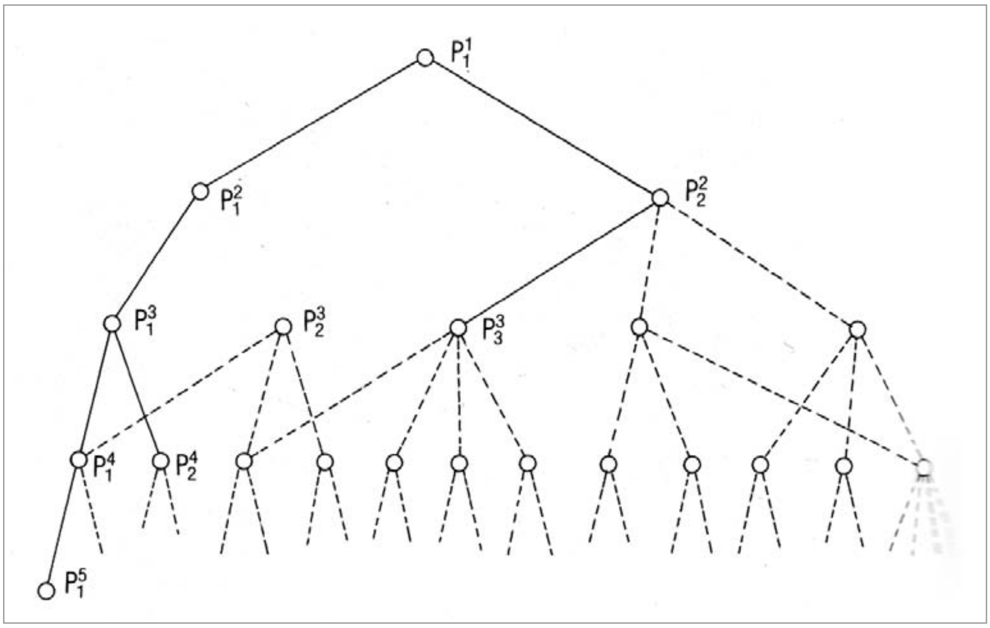


Figure 2.8: A hierarchical problem space tree diagram, from Rowe (1987: 68).

This diagram illustrates how a choice of two variables at each decision point may result in an extensive problem space (Rowe, 1987: 67). Solving a well-defined problem may thereby include complicated decision-making, due to the number of choices available and the implication of connections (Rowe, 1987: 67). Most often the designer iterates within different levels and may find contradictory relations. If such relations do not self-cancel, then re-synthesis of information is required, further complicating the decision-making (Rowe, 1987: 73). The tree diagram also illustrates the difference between theoretical models of well-defined and ill-defined problems; the above model does not indicate implications *between* the linear paths. Such interrelations are taken into account in models of ill-defined problems.

2.4.2.2 Ill-defined problem spaces and co-evolution

Models of ill-defined problem spaces reflect a parallel relationship between the problem and solution. Cross (2000: 15) combines a problem space with a parallel solution space as an overall dimension, and includes a sub-problem and sub–solution space as a sub-dimension [figure 2.9]. The spaces exist in a 'symmetrical and communicative relationship' (Cross, 2000: 42), where potential solutions are considered whilst setting the problem; the problem and solution co-evolve.

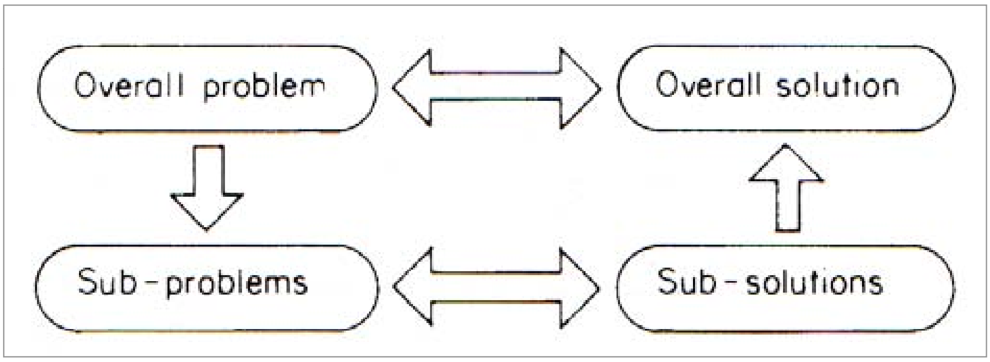


Figure 2.9: The design space including problem space and solution space (Cross, 2000: 42).

When seen across time, the co-evolution may progress logically and iteratively from problem to sub-problems, over sub-solutions, to a solution. Dorst and Cross (2001: 11) present a problem and solution space co-evolving over time [figure 2.10]. Between each stage the designer moves her focus and transfers information – 'fitness' – from the problem space to the solution space and on to the evolved problem space *etc*.

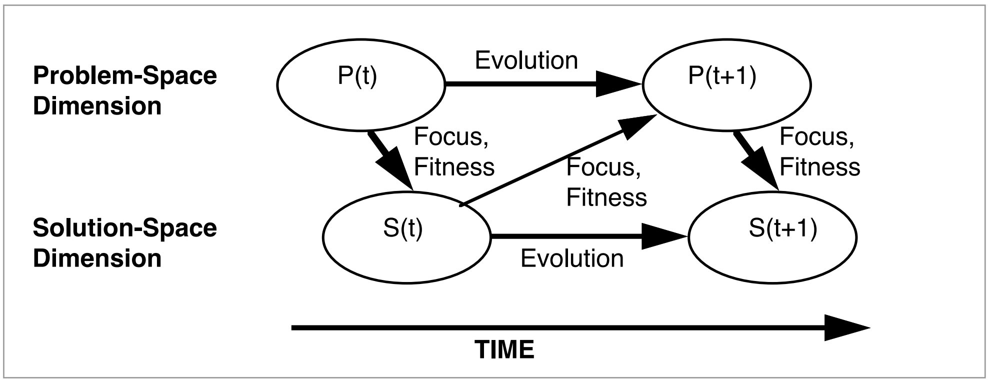


Figure 2.10: Co-evolution model (Dorst and Cross, 2001: 236)

The creative act, therefore, involves bridging the two spaces, rather than 'leaping' from one to the other (Cross, 2000: 42). As related to Schön's (2006) description of problem setting [section 2.4.2 p. 42] the designer identifies features from the problem space to attend to. Then she pairs them with features from the solution space, to identify the context within which to explore them (Cross, 2000: 42). The feed of 'focus' and 'fitness' shown in figure 2.10 thereby illustrates the interrelations which are excluded from the tree diagram showing a well-defined problem space [figure 2.8, p. 44]. These interrelations may be complimentary and sometimes conflicting. To identify the information transformation rationale, thereby, requires analysis of the problem and its sub-problems, their relation to solution and sub-solutions, as well as the feed of 'focus' and 'fitness' during the co-evolution. For the purpose of analysis in this research enquiry, Cross (2000) and Dorst and Cross (2001) enable identification of deeper details in the nuances of decision-making, *eg,* how one decision may affect the rationale for interrelated graphic tactics. Figure 2.11 shows the hierarchical relationship between the concepts of the design task, problem setting, and problem-solution co-evolution; how each concept enables identification of deeper detail about the information transformation process and rationale – or broader focus in a bottom-up approach.

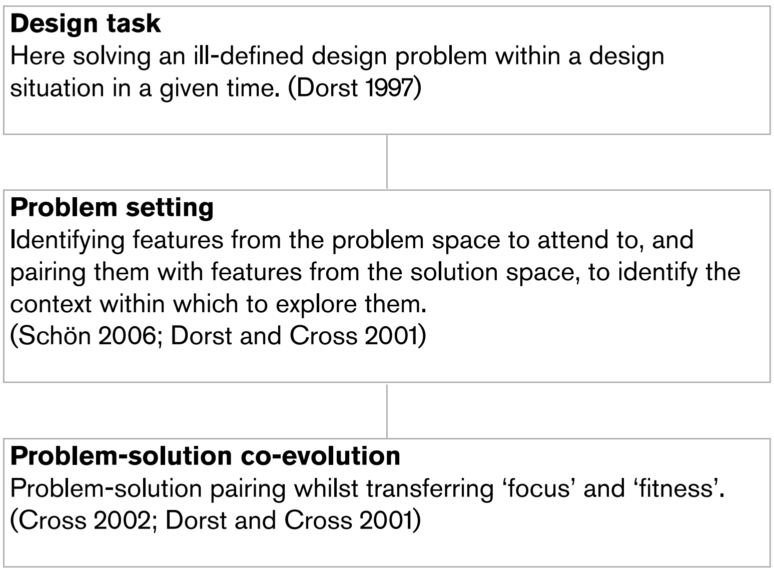


Figure 2.11: Hierarchy of theoretical concepts, each enabling deeper detail of the information transformation process and rationale.

These theoretical models enable a process-oriented analytical perspective, which identifies how decisions are made and affect each other over time in the information transformation process; *ie,* how the participants navigate the design situation when performing the design task. An additional analytical perspective applied in this research enquiry represents a cross-sectional view of the design situation. This identifies the features which the participants choose to attend to, their approaches, and reasoning at significant choice points (Schön 2006) when navigating the design situation.

2.4.3 Choice points in the design situation

The design situation comprises the design problem and the situational context (Dorst, 1997) within which it is solved. Design problem in this enquiry refers to the visual composition challenge facing a designer as part of information transformation, *ie,* information categorisation in an ecological cycle network diagram. The situational context relates to the environment of individual publisher. Schön (2006) describes the way a designer moves within a design situation as a 'reflective conversation with the materials of the design situation' (2006: 76). Through information gathering and problem setting, the designer imposes his or her own understanding of the situation. The designer defines the problem as she sees it, 'seeing-as' (Schön, 2006: 129), thus creating a theoretical understanding which needs testing through 'doing-as' (Schön, 2006: 141). During this practical process 'knowing-in-action' and 'reflection-in-action' (Schön, 2006: 50-59) take place. The former relating to tacit knowledge, guiding the latter, which is the designer's ability to learn and reflect whilst practising. Schön (2006: 99) describes the designer's journey through a 'web of moves':

> As he reflects-in-action on the situation created by his earlier moves, the designer must consider not only the present choice, but the tree of further choices to which it leads, each of which has different meanings in relation to the systems of implications set up by the earlier moves. Quist's [a designer] virtuosity lies in his ability to string out design webs of great complexity. But even he cannot hold in mind an indefinitely expanding web. At some point, he must move from a "what if?" to a decision which then becomes a design node with binding implications for further moves. Thus, there is a continually evolving system of implications within which the designer reflects-in-action .
> (Schön, 2006: 99).

Thereby a choice point (Schön, 2006) is a point in the process at which a (sub)-problem-solution pairing happens (Dorst and Cross, 2001). Design here seen as an argumentative process in which organising principles guide the 'network of reasoning' taking place (Rittel and Webber, 1973). Each process stage may have different organising principles, dependent on the dominant task and problem conditions (Rowe, 1987: 36-37). Figure

2.12 summarises the hierarchical relationship between the just outlined theoretical concepts of the design situation, situational context, design problem, and significant choice points.

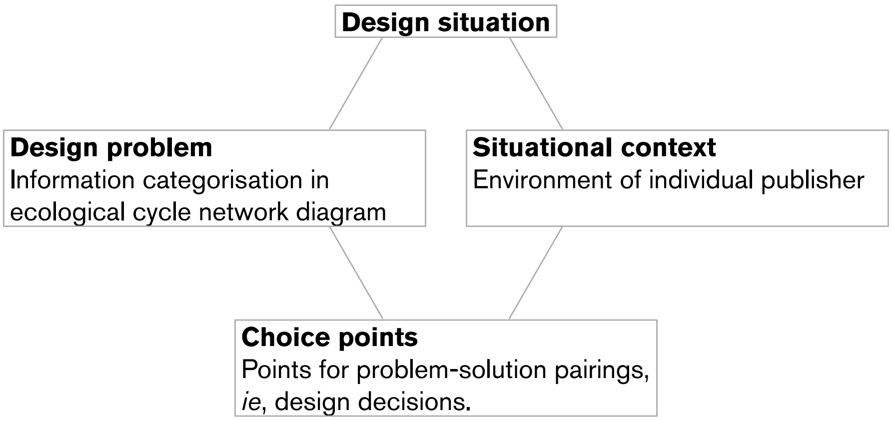


Figure 2.12: Hierarchy of theoretical concepts to identify the design situation, each enabling deeper detail of the information transformation rationale.

An analysis of the organising principles at significant choice points thereby provides further detail on the transfer of 'fitness' and 'focus' (Dorst and Cross, 2001) in the information transformation process. It identifies the features in the design situation, among which the participants have to navigate, and how decisions at one choice point affect decisions at interrelated points, as design constraints.

2.4.3.1 Design constraints

Design constraints are features in the design situation that may affect the decision-making. Archer (1984: 7) describes design constraints as 'hedging' the design problem. Within these 'hedges', the designer has a certain 'room for manoeuvre' which can be an:

- 'open design situation' in which many solutions are possible,
- 'inevitable solution' so constrained that the solution is virtually prescribed,
- 'broken up field of freedom' – a middle ground where a limited number of different solutions are possible.

Lawson (2006) further defines constraints as internal and external; enabling analysis of whom is responsible for design decisions. Internal and external constraints may originate from all participants (2006: 97), the essential feature being the level of freedom offered for the designer. External constraints mainly originate from the situational context, *eg,* the constraints imposed on a diagram from its relation to other page elements, to audience level, or curriculum purpose. Internal constraints originate from within the diagram (2006: 92-93), *ie,* here the composition of graphic objects, graphic syntax, and interrelations between graphic tactics and the graphic strategy. Internal constraints may thereby, in theory, offer the designer greater room for manoeuvre when compared to external constraints (2006: 97).

Constraints are often termed as, *eg,* parameters or requirements (*eg,* Dorst, 1997) as designers may perceive them as stimuli for their creativity, rather than limitations (Crilly, 2005). The designer's own parameters may also broaden the design situation. Such 'enabling constraints' (Rowe, 1987: 37) allow the designer's organising principles and vision for the solution to become an integral part of the solution. Analysing the features which the participants choose to attend to at each choice point, variation in their approaches and the reasoning guiding the decision-making thereby identifies how internal and external design constraints may affect the information transformation rationale. An essential feature for identifying design constraints is the design brief (Lawson, 2006).

2.4.4 The design brief

The design brief, or problem statement, represents the opening event in the design process; providing the goals, constraints, and criteria against which the interim stages and final output is evaluated (Archer, 1984: 7, Cross, 2000: 11, Lawson, 2006: 93, Dorst, 1997). The level of detail specified in a brief varies from each project, forming the initial room for manoeuvre (Archer, 1964/1984). As such, the development of the brief is here of equal interest to investigating the translation of the brief into a diagram. Analysing the decision-making during the brief development, in addition to the translation process, here identifies the constraints accommodated, the implicit and explicit visual references used, and evidence of their influence on the design output (Crilly, 2005: 176). This enables identification of the fundamental information transformation rationale, *ie,* the decision to include a diagram in the first place, the reasoning for the specified constraints, and how they affect the translation process, hence visual output. This additional focus on the brief development process in turn necessitates analysis of the different participants taking part in each of the two processes, the delegation of responsibilities, and how this may affect the information transformation rationale.

2.4.5 Participants in design process

Zeisel (1984) presents a model for identifying client-designer-user relationships in a design situation; describing 'cultural gaps' in the relations between designer-user and client-user [figure 2.13], whereas the designer and client, according to Zeisel, share a common image of life (1984: 34). Crilly (2005: 150) develops this model by indicating the participants initiating the product and the communication links [Figure 2.14].

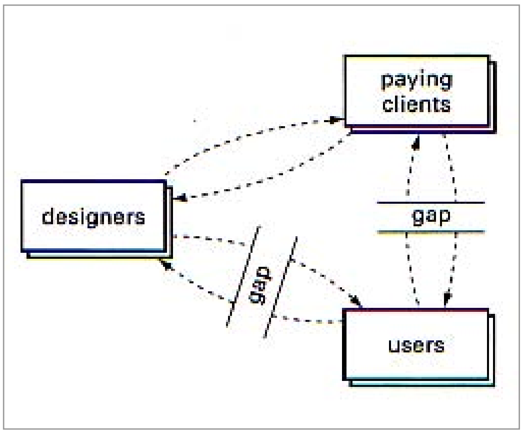


Figure 2.13: Designer-client-user relation from Zeisel (1984: 35)

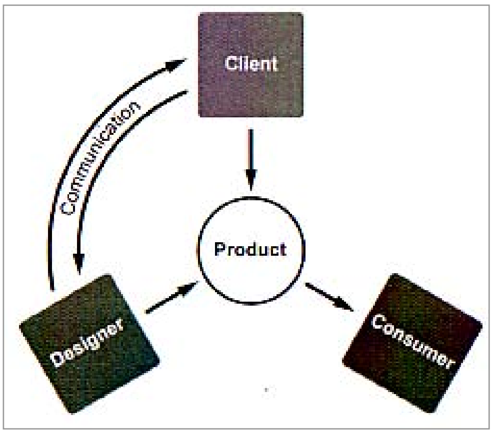


Figure 2.14: Designer-client-user-product relation from Crilly (2005: 150)

Such mapping of participant constellations enable analysis of the delegation of responsibility within the design situation – and the effect on the visual output – by identifying the design functions and the participants who are overtly or silently responsible for the decision-making.

2.4.5.1 Design functions and silent design

Dumas and Mintzberg's (1991) framework for design activities within organisations takes into account the participants' different understanding and values of design, as well as the different levels of contribution from different participants. Their model comprises a trichotomy of industrial design functions: engineering, ergonomics, and style – 'function', 'fit', and 'form' [figure 2.15]. 'Fit' providing an ergonomic-based link between 'form' and 'function'.

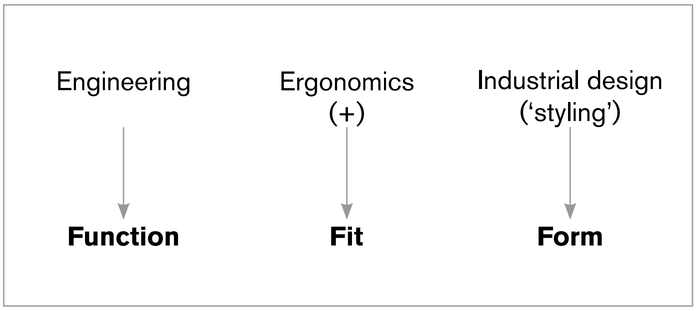


Figure 2.15 : Dimensions of design by Dumas and Mintzberg (1991: 27).

When related to an ecological cycle network diagram, 'function' relates to biological accuracy, 'form' to the aesthetics. Dumas and Mintzberg (1991) sub-divide 'fit' into two entities: 'technical fit', located between product interface and user, and 'conceptual fit' between the nature of the product, user needs, and production possibilities. 'Technical fit' here relates to the principles of graphic syntax; providing cognitive ergonomics to align the visual output with the user's perception process (Proctor and Proctor, 2006). 'Conceptual fit' relates to meeting the curriculum purpose and the pedagogical aims of a diagram in a textbook with available printing technology.

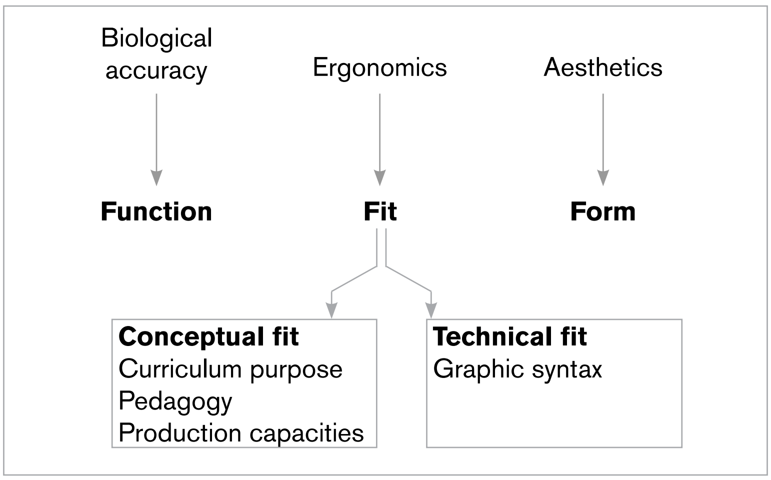


Figure 2.16: Dumas and Mintzberg (1991: 27) adapted to this research enquiry focus.

As such, the 'fit' design function represents the core information transformer responsibility and skills set, as defined in this research enquiry [section

2.1.3, p. 27]; 'technical fit' comprising the essential expertise. Analysing the delegation of responsibility in the current professional practice context enables identification of the participants who are formally or informally involved in deciding graphic strategies and graphic tactics.

Significantly for this research enquiry the definition of a 'designer' is altered by Gorb and Dumas (1987). They define 'silent design' as design decisions taken by people who are not formally acknowledged as designers. Managers, in particular, practice 'silent design' through their essential focus on the conceptual 'fit', overseeing this aspect across the 'function' , 'fit', and 'form' design functions. Hence a 'client' participant role represented in the models of Zeisel (1984) or Crilly (2005) [figures 2.13 and 2.14, p. 50] may be responsible for any of the 'form', 'fit', 'function' design functions, as 'silent designers'. When viewed through this theoretical context, the information transformation process becomes a network of interrelated creative and management activities; partly managing the physical and creative product development, partly managing the different viewpoints and expertise present in the participant constellation. The variation in such organic design situations may here be identified through models of design activities.

2.4.5.2 Models of design activities

Dumas and Mintzberg (1991) outline five models of design activities, identified through the participants responsible for the 'function', 'fit', and 'form' design functions:

- *Encompassed design – single function* - a process where one type of participant is in charge of all three functions, *eg,* engineers designing a road.
- *Decomposed design - isolated functions*
  Fragmentation of process into each function, enabling delegation of each task to separate, isolated participants. Often seen for 'mature' or standardised products *eg,* a ballpoint pen.
- *Dominated design - leading function*
  A hierarchical set up in which one person or group is in charge, 'taking the lead' over the other separate functions *eg,* stylists deciding the form of a car, engineers then developing the mechanical inside, before passing the project to the ergonomists, production, marketing *etc.*
- *Visionary design (championed)*

A version of dominated design in which *eg*, a leading person dictates the product development throughout all three design functions.

- *Cooperative design – interacting functions*
  Encourages interaction between participants, working in a collaborative team set up.

'Cooperative design' is suggested by Dumas and Mintzberg in response to perceived shortcomings of the other four (1999: 29); arguing that 'cooperative design' increases availability of design expertise, bridges communication gaps between expertise, and encourages interactive communication between participants. In the context of this research enquiry, Dumas and Mintzberg's model enables the integration of research findings [chapter 7]. Identifying the model of design activities occurring within a professional practice setting here enables analysis of interrelations between the situational context and the design problem. This reveals how the delegation of formal and informal responsibilities may affect decisions about graphic strategies and the precision of graphic tactics.

2.5 Design practice in educational publishing

The professional practice context investigated in this research enquiry is design practice in educational publishing. The defining feature of this practice is adherence to the national curriculum when developing textbooks. Significant choice points and participants within the design process in educational publishing process are here identified from existing literature. These aspects inform the structure of the interview data collection when identifying the information transformation rationale.

2.5.1 Literature on design practice in educational publishing

Educational publishing is in this research enquiry defined as publishers specialising in producing learning material such as textbooks. Textbooks are distinct from popular science publications by being part of a series adhering to the national curriculum. The literature search in this research enquiry has uncovered a sparse research focus on description of the design process in educational publishing. Two general texts focus particularly on the production of educational textbooks (Educational Publishers Council, 1983; Lepionka, 2008), whereas Bailey (1990) provides an analytical study of the economic perspective of the general publishing process. Of particular interest for this research enquiry is Puphaiboon (2005), a PHD-thesis presenting a participatory-design method for producing diagrams for teaching mathematics (UK key stage 2, 8-10 year age groups).

Given the mathematics, task-oriented, and user-centred context, the majority of Puphaiboon's findings are not directly relevant to this enquiry. However, Puphaiboon interviewed six in-house designers, one at each main UK publisher, to investigate the current design process for producing mathematic diagrams in textbooks. Based on this he suggests a range of shortcomings in relation to producing effective mathematics diagrams. Evans *et al* (1987) describe the publishing design process based on interviews with nine Canadian educational publishers. In contrast to Puphaiboon's focus on designers only, Evans *et al's* nine interviewees represent several different roles in the process, including editor, art director, design director, and production manager. Unfortunately, the interviewees were not directly linked to the visual output analysed in the study from Evans *et al*, leading to general interview questions, and answers, which also have a broader focus than biology or even science subjects.

To complement the sparse academic sources relevant for this thesis, publishers' web sites were searched for current information on their processes. Oxford University Press (OUP, 2009), Pearsons Educational (2009), and Alínea [Denmark] (2009) offer such information to prospective authors. This enables an overview of the general process stages of educational publishing, from which significant choice points may be identified.

2.5.2 General process stages of educational publishing

Several of the reviewed texts stress that the details of an educational publishing process varies according to the individual publisher and the particular projects (*eg*, Educational Publishing Council, 1983: 1). However, the development of a textbook generally progresses through five major stages: synopsis/book concept, editorial process, design, production, and distribution/sales (Lepionka, 2008: 29). These stages are summarised visually in figure 2.17, excluding possible iterations.

Figure 2.17: General book development stages.

The *synopsis* stage includes considerations about finance, marketing, general editorial book concept, and sample page designs. The *editorial* stage focuses on forming the textual content before moving on to the *design* stage in which the drafted manuscript takes its shapes as a physical book design. Once the textual content and book design is approved, it moves into *production* stage in which printing and binding takes place, before the final distribution to booksellers (*eg,* Educational Publishing Council, 1983). Significant choice points (Schön, 2006) in relation to the design of diagrams may be identified from these general process stages, to inform the analysis of the design situation in this research enquiry.

2.5.2.1 Choice points in relation to diagram design

Two types of design briefs are developed during the publishing process: the book design brief developed during the synopsis stage and the artwork brief developed within the editorial stage. The book design brief specifies the number of pages, quantity to print, hardback/paperback, trim size, number of tables and illustrations, printing specifications, and paper stock (OUP, 2009, Bailey, 1990). The artwork brief, meanwhile, is a significant choice point for analysis in this research enquiry; a standard template specifying the position and layout of the visual, style, textual content, font, size, and caption heading (Puphaiboon, 2005: 85). The artwork brief may also include a sketch of the diagram or visual references (Puphaiboon, 2005; Evans, 1987), all of which are evaluated by the editor. These represent significant choice points, as does the translation of the brief into a diagram, and the evaluation of the final diagram (Puphaiboon, 2005; Evans, 1987).

Two additional choice points are case-specific decisions regarding an ecological cycle network diagram. These relate to deciding the type of diagram and the biological content to include. The formal roles involved with the decision-making at these choice points may also be identified from existing literature. This reveals the participants to interview in this enquiry for identifying the current information transformation rationale.

2.5.3 Participants in educational publishing

Credited in existing textbooks are formal roles such as editor/publisher, series editor, author, marketing department, production department, art director, designer, illustrator, picture researcher, photographer, and external evaluators (*eg*, Fullick, 2001 or Bjerrum *et al*, 2005). Some of these *eg*, designers and illustrators are credited as external companies. Table 2.2 [next page]outlines the main participant roles, as synthesised from Educational Publishing Council (1983) and Lepionka (2008).

Participant	Role
Commissioning editor	· Commissions external participants · Overall responsibility from first draft to launch
Publisher/editor	· Oversees practical activities: content structure, development, design, and production
Copy editor	· Proofreading textual elements
Author	· Textual content · Development of artwork brief
Book designer	· Book layout template · Laying out final manuscript · May supply diagrams
Illustrator	· Original pictorial artwork: full illustrations, diagrams, or pictorial objects for diagrams
Picture/media researcher	· Researches existing artwork for reproduction

Table 2.2: Participant roles. Synthesised from Educational Publishing Council (1983) and Lepionka (2008)

Four formal roles emerge here as involved in decision-making, at one or more of the choice points listed above: book designer, illustrator, author, and editor. These roles inform the interview strategy in this enquiry.

Book designers and illustrators

All reviewed literature agree on the book designer, or illustrator, as translating the artwork brief into a diagram. Detail differs about the entrance of the book designer in the process (OUP, 2009; Lepionka, 2008) and the designer's individual level of engagement in decisions about diagram designs (*eg*, Pearson 2009; OUP, 2009). The previously listed brief template specifications [section 2.5.2.1, p. 56] here limits the designer's influence on decision-making (Puphaiboon, 2005: 86). Evans *et al* (1987: 87) and Pearsons (2009) describes the author as specifying the illustrations to include, while Puphaiboon (2005) found the artwork brief set by author, marketing and finance, and editors.

Authors and editors

Within the mathematics context, Puphaiboon found that authors often draw a sketch of the wanted visual or, in some cases, literally brief the designer to re-use a previous diagram with some modifications. Such author-centred process casts the author and editor in crucial roles for the information transformation; underscoring firstly, the need for investigating both the brief development and translation process, and secondly, the need for identifying the delegation of skills in relation to design functions, when identifying the information transformation rationale. This is particularly so given that Puphaiboon (2005: 88-89) and Evans *et al* (1987: 87) found the author-centred approach leading to non-systematic diagram evaluation criteria based on brief content: the diagrams are reviewed for accuracy in copying the author's sketch and an aesthetic evaluation mainly in relation to sales purposes. The artwork brief itself is evaluated by editors according to appropriateness for the particular teaching content, rather than the communication effectiveness. Evans *et al* (1987: 90) further found 'trial and error, past experience, personal intuition, and what had sold previously' important factors for deciding on illustrations to include, whereas research had very limited influence on the decision-making. Puphaiboon (2005: 88-89) found designers reluctant to question the brief, due to a perception of authors as subject experts, hinting at a cultural divide (Zeisel, 1984). Instead, sales figures and the editor's acceptance represent the designer's general success criteria. Both studies indicate minimal, if any, direct communication between author and designer, leaving the editor as a middle-man.

2.5.3.1 Participants for interviewing

The reviewed literature provided valuable indicators to participants who potentially influence the decision-making at the identified choice points. To uncover greater detail on the features attended to at each choice point, variation in approaches and the reasoning, the interview strategy of Evans *et al* (1987) and Puphaiboon (2005) are in this research enquiry synthesised. This entails investigation along the critical path of the information transformation process; focusing on the artwork brief development and evaluation, translation, and evaluation of the final diagram. Authors, editors, designers, and illustrators are thereby interviewed, to identify the network of reasoning guiding choice points in both brief development and translation stage. The interview questions build on Crilly (2005) for the brief development and Puphaiboon (2005) for the translation stage. Furthermore, this thesis develops the strategy of Evans *et al* (1987) by integrating findings about design decisions with the related visual analysis findings.

At this point it is appropriate to identify the final branch of Zeisel's (1984) [figure 2.13, p. 50] participant constellation. The user group – readers in this thesis – here includes both teachers and pupils, using textbooks to teach and learn respectively. The end-users are pupils following the national curriculum for age groups 14-18. The curriculum, as the defining feature of educational publishing, represents a general external constraint on the rationale for transforming information into ecological cycle network diagrams.

2.5.4 National curriculums

Both Denmark and the UK have governmental educational departments and regulators to outline approaches to learning, over-arching themes, and statutory expectations within education. These are published in formal legislation, in the form of curricula (DFCSA/QCA, 2007; UVM, 2007 and, 2009). The general curriculum information relating to the 14-18 year age groups is summarised in table 2.3.

Age group	**Denmark**	**UK**
14-16 age group	*Long term targets:* 'Fælles mål' [Shared aims] *Short term targets:* Trin mål [stage aims]	*Long term targets:* National Curriculum Key stage 4 *Short term targets:* Exam specifications
16+	*Long term targets:* Gymnasium bekendtgørelsen' [The Gymnasium legislation] *Short term targets:* n/a	*Long term targets:* National Curriculum A-levels *Short term targets:* Exam specifications

Table 2.3: Curriculum information relating to age groups.

In the UK three bodies award the qualifications, each interpreting the curriculum aims into their own set of exam specifications (AQA, 2007; Edexcel, 2007; OCR, 2007). In Denmark qualifications and exams are centralised governmental responsibilities. The Department of Education develops long term targets [slutmål] and short term targets [trinmål] for all subjects. The former similar to the UK National Curriculum and the latter similar to the UK exam specifications. In this thesis, exam specifications is used as a general term for the short term targets in both countries. In both countries the exam specifications are further separated into different levels *eg,* foundation and higher in the UK[3].

When outlining general science skills, both sets of specifications include the visual language of science as a subject to be taught, interrelated with the specific biological themes:
The Danish 'Shared Aims', for example, stress the importance of students working with modelling and 'other visualisation' (UVM, 2007; 2009). They outline four main natural science competencies to acquire: empirical skills, representation skills, modelling skills and contextualisation skills. The representation skills include, among other sub-skills, 'symbols and representations' (UVM, 2007; 2009).

In the UK, the 'knowledge, skills, and understanding' section states that:

> 'pupils should be taught a) how scientific data can be collected and analysed, b) how interpretation of data, using creative thought, provides evidence to test ideas and develop theories c) how explanations of many phenomena can be developed using scientific theories, models, and ideas…' (DFCSA/QCA, 2007: 221)

Further to this, the section 'communication skills' (DFCSA/QCA, 2007: 222) state that :

> 'pupils should be taught to… c) present information, develop an argument and draw a conclusion, using scientific, technical and mathematical language, conventions, and symbols, and ICT tools' .

At a general level, in both countries, this curriculum-led incentive may thus form part of the fundamental rationale for including an ecological cycle network diagram. This curriculum focus on visuals is directly linked with diagrams' positive cognitive effects [section 2.2, p. 30] – *ie,* making spatial relationships meaningful and pattern recognition – as they have influenced the development of the network diagram as a scientific visual convention. In terms of detailing ecological cycle subject content, the Danish specifications are less prescriptive than their UK counterparts.

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3 The scope of this research enquiry necessitates only a general outline of the exam specifications. Further detail on the choices available within different levels is omitted *eg*, Denmark has four overall types of A-levels.

2.5.4.1 Specification of ecological cycle content

The exam specification may inform the information transformation rationale through description or prescription of course content. The two countries here differ in level of constraint; generally the Danish outlines are less prescriptive than the UK.

Within the UK, the three awarding bodies operate with different levels of prescriptiveness in subject detail for ecological cycles. All three specifications include a simple cycle concept description, information types such as processes and some organisms, as well as areas for contextualisation. Only one exam specification explicitly mentions a diagram – the UK's Edexcel GCSE:

> '…describe the importance of nitrogen in the environment, including the roles of: nitrogen fixing bacteria, decomposers, nitrifying bacteria, denitrifying bacteria as shown and interpreted in nitrogen cycle diagrams' (Edexcel, 2007: 83).

Edexcel further specify one type of organism and three processes, assessing students:

> 'on their ability to demonstrate an understanding of and interpret data on the carbon cycle as representing the flow of carbon in nature, including the roles of microorganisms, photosynthesis, respiration, combustion.' (Edexcel, 2007: 83).

AQA and OCR include several processes *eg,* photosynthesis, respiration, feeding, decomposition. They also provide increasingly detailed description of each of these carbon cycle elements, for example:

> 'The constant cycling of carbon is called the carbon cycle. In the carbon cycle: carbon dioxide is removed from the environment by green plants for photosynthesis…' (AQA, 2007: 44).

In the Danish exam specifications, the subject content are left at the more abstract level of 'matter cycles' or 'ecological systems'. The 'long term targets' for biology here state that students after ninth grade should have obtained skills and knowledge enabling them to:

> 'identify composition and decomposition of organic matter, matter cycles, and energy flows.'[4](UVM, 2009: 4).

4 Translated by researcher

The 'short term' targets similarly leave the detail open:

> [students should be able to] '…explain the biological effect of energy flows and selected cycles in different ecological systems…explain causes and effects of natural and human changes to ecological systems and their influence on biological diversity.' (UVM, 2009: 7).

Thus the publisher is left to decide the detail. For the Danish equivalent to A-levels, the exam specification is further abstracted, one minimalisticly stating:

> 'ecology, including investigation of an ecosystem',

and

> 'succession, energy flow, and C- and N-cycles in selected ecosystems'. (UVM, 2007: 4)

Thereby the Danish exam specifications leaves a more flexible room for manoeuvre for the publishers to work within, in relation to diagram content. UK publishers are somewhat more constrained by this variable, with specific content given. Extending this research enquiry to both countries, enables analysis of how the different level of prescription by this defining external constraint may affect the information transformation rationale; as well as offering contributions to information design practice in both countries.

Summary

This literature review has provided a theoretical underpinning for the two *research strands*, and the integration of the research findings in this enquiry.

The field of study was defined as information design, comprising a practical field and the academic study of practice, synonymous with information transformation. Information transformation was explained as comprising a strategic and tactical level; the tactical level recursively separated into graphic strategy and graphic tactics.

General reasons for including an ecological cycle network diagram in a textbook were found, based on positive cognitive effects.

Graphic syntax theory was reviewed and Engelhardt (2002) was selected for application in the visual content analysis in the *first research strand* of this enquiry.

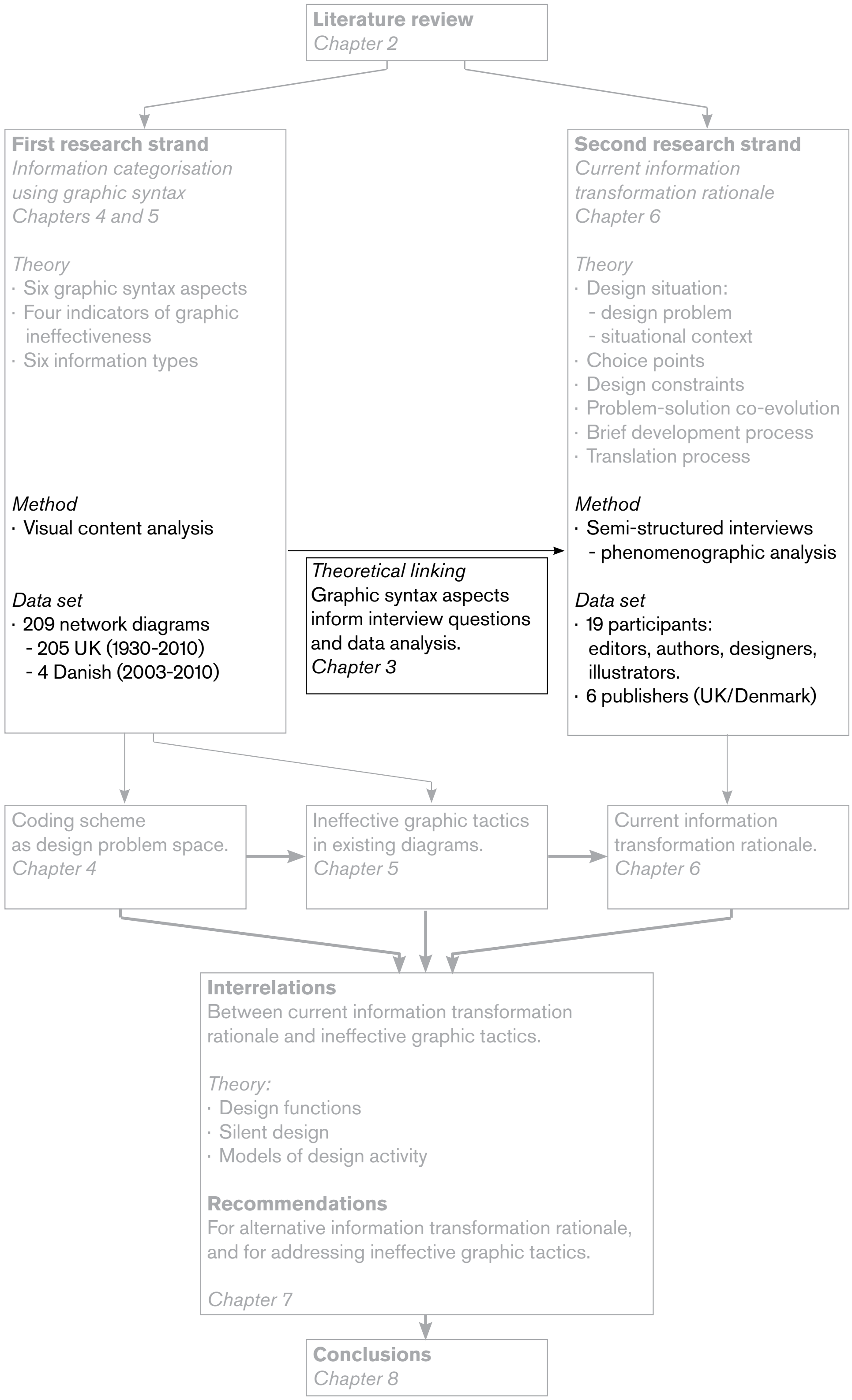
To inform the *second research strand* – and to identify the information transformation rationale – the professional practice context was defined as the situational context of the design situation. Information transformation in this context comprises the brief development and translation processes.

It was argued that the information transformation rationale may be identified through the features attended to at significant choice points; and through analysing the delegation of responsibility for design functions in the process.

Significant choice points in the brief development and translation process, and the formal roles involved in decision-making were identified, informing the interview data collections.

Content specifications for ecological cycles were identified from the Danish and UK exam specifications.

3 Methodology


Literature review
Chapter 2
First research strand
Information categorisation using graphic syntax
Chapters 4 and 5
Theory
· Six graphic syntax aspects
· Four indicators of graphic ineffectiveness
· Six information types
Method
· Visual content analysis
Data set
· 209 network diagrams
- 205 UK (1930-2010)
- 4 Danish (2003-2010)
Second research strand
Current information transformation rationale
Chapter 6
Theory
· Design situation:
- design problem
- situational context
· Choice points
· Design constraints
· Problem-solution co-evolution
· Brief development process
· Translation process
Method
· Semi-structured interviews
- phenomenographic analysis
Data set
· 19 participants:
editors, authors, designers, illustrators.
· 6 publishers (UK/Denmark)
Theoretical linking
Graphic syntax aspects inform interview questions and data analysis.
Chapter 3
Coding scheme as design problem space.
Chapter 4
Ineffective graphic tactics in existing diagrams.
Chapter 5
Current information transformation rationale.
Chapter 6
Interrelations
Between current information transformation rationale and ineffective graphic tactics.
Theory:
· Design functions
· Silent design
· Models of design activity
Recommendations
For alternative information transformation rationale, and for addressing ineffective graphic tactics.
Chapter 7
Conclusions
Chapter 8

Contents

3 Methodology

3.1 Research strategy

The research strategy (Robson, 2002) – or research design – in this enquiry combines visual content analysis, semi-structured interviews and phenomenography to meet the defined aims and objectives. The interview guide here provides a crucial link between the two *research strands*, enabling integration of the research findings. Together this represents a practice-led naturalistic research enquiry.

3.1.1 Research strands with multiple methods

A defining feature of the research strategy for this research enquiry, is the tracing of a visual output through its theoretical and professional practice context. This strategy was guided by questioning how ambiguities come to exist in ecological cycle network diagrams in science textbooks for the 14-18 years age groups; what theoretical complications may lead to graphic ineffectiveness, and which features affect the rationale when transforming a manuscript and visual references into a published diagram within design practice in educational publishing. The research enquiry was structured around the two *research strands* as reflected in this thesis; the research strategy developed through pilot analyses within each strand.

Visual content analysis was applied in the *first research strand*, to analyse a data set of 209 collected ecological cycle network diagrams (205 UK/4 Danish). This method enabled a systematic analysis of information categorisation using graphic syntax in existing visual output. The units of analysis – forming the coding scheme for the analysis – here revealed the potential theoretical complication involved when categorising information in an ecological cycle network diagram. This identified the design problem space investigated in this research enquiry, exposing the internal design constraints in the form of general ineffective graphic tactics [chapter 4]. The frequencies of the coding values, the units of analysis, in turn revealed the ineffective graphic tactics present within existing visual output [chapter 5].

Semi-structured interviews with 19 editors, authors, designers, and illustrators (UK and Denmark) were conducted to meet the aims of the *second research strand*. Semi-structured interviews allowed the interviewees to reconstruct events and describe their approaches to designing a diagram (Bryman, 2004: 339). These individual descriptions enriched the data when compared to quantitative, structured interviews, or surveys. Crilly (2005: 83), for example, also found that increasingly open conversations with designers offered additional insights about design constraints not provided by directly answered questions.

The collected interview data were analysed using phenomenographic analysis method (Bowden, 2005). Phenomenography enables mapping of a phenomenon – here information transformation – through identifying and categorising variation in the interviewees' approaches to their practice. The analysis method here enabled identification of the features attended to, the approaches, and the reasoning guiding the decision-making at each significant choice point (Schön, 2006; Lawson, 2006). This revealed how the information transformation process evolves (Dorst and Cross, 2001) during the brief development and translation processes, as well as the formal and informal delegation of responsibility in relation to design functions (Dumas and Mintzberg, 1991).

To meet the third and fourth aims of this research enquiry – identifying how design decision may affect graphic tactics, and developing an alternative information transformation rationale – the different sets of research findings were integrated. This required systematic, theoretical linking between the two *research strands*, a bridge provided by the interview guide.

3.1.1.1 Linking research strands through interview guide

An interview guide is the list of questions used when conducting semi-structured interviews (Robson, 2002). The development of the guide includes formulation of the interview questions and their sequence. The content of the interview guide – for this research enquiry – was crucial for enabling the research strategy of tracing a visual output through its theoretical and professional practice context. The guide was structured based on the analysed graphic syntax aspects and the findings from the pilot visual content analysis [section 3.2.3, p. 76]. The questions were formulated to identify the interviewees' considerations at choice points in the brief development and translation process [section 3.3.3, p. 85]. The structure of the interview guide in turn provided the structure of the interview data analysis, which identified the variation and similarity in the rationale at each choice point. Thus the analysed graphic syntax aspects formed a link between the two strands. This link enabled identification of the situational context which surrounds the design problem and the features within it which may affect the design decision-making. The theoretical link between the two *research strands* thereby allows for integrating the resulting research findings, hence meeting the third and fourth aim of the research enquiry.

3.1.1.2 Integrating research findings

Identifying the rationale at each choice point in the interview data analysis – including the delegation of responsibility for each design function – revealed the models of design activities (Dumas and Mintzberg, 1991) applied in current practice. The interrelations between the models of design activity, potential theoretical complication, and the identified ineffective graphic tactics, in turn uncovered plausible implications of the decision-making in current practice in relation to ambiguities in existing visual output. Based on these integrated findings it is possible to suggest a set of recommendations for an alternative information transformation rationale. These recommendations build on suggestions from the interviewed participants, the integrated research findings, and information design theory.

The *research strands* and their theory-based linking are outlined in the conceptual frame work (Leshem and Trafford, 2007) in figure 1.4 [p. 20]. Based on the explicit conceptual framework, precise aims and objective for each strand, and for their linking, the research strategy may be defined as information-seeking, or 'pre-structured' (Miles and Huberman, 1994: 83-84). The resulting outcome represents a 'meta-reflection-on-practice' (Schön, 2006; Cherry, 2005).

3.1.2 'Meta-reflection-on-practice'

The methodology defined for this research enquiry facilitates a 'meta-reflection-on-practice' (Schön, 2006; Cherry, 2005) in which a practitioner stands back and observes a specific area within a field. In this research enquiry, this relates to looking across the field of educational publishing – rather than a single publisher – and bridging the theoretical and professional practice context. The limitations of this strategy is the level of abstractness of findings resulting from both visual content analysis and phenomenographic data. Here a systematic review of individual graphic tactics in the data set is prioritized above reviewing diagrams as individual cases, and plotting the landscape of information transformation is prioritized above detailing individual routes across the terrain. In this case the 'meta-reflection-on-practice' aims at meeting the vision for practice-led research outlined by Woolley (2000b). This consist of simultaneously reflecting on practice, and identifying theoretical and practical obstacles to enhancing future practice [section 1.5.2.1, p. 18]. This outcome and approach positions this research enquiry in a wider research paradigm of naturalistic enquiry.

3.1.3 A naturalistic enquiry

The thesis is placed within a constructivist view of research, looking at the identified information transformation rationale in educational publishing as an 'emergent reality in a continuous state of construction and reconstruction' (Bryman, 2004: 17). A narrower label within this constructivist paradigm is 'naturalistic enquiry' (Robson, 2002: 27), which has previously been applied within design research (*eg,* Dixon, 2001; Bunnell, 1998; Wheeler, 1996). A naturalistic enquiry involves the collection of data from an existing environment (Bryman, 2004). Furthermore this type of enquiry includes:

- Utilising the researcher as a data gathering instrument
- Working within the natural setting and context of the enquiry
- Inductive data analysis, unfolding with the emergent enquiry,

Of particular design-specific interest is the legitimation of tacit knowledge as an addition to other types of knowledge.

This thesis takes a less well-trodden path within the established naturalistic enquiry framework. This happens by applying phenomenographic analysis instead of traditional research strategies such as grounded theory, ethnography, or a case-study (*eg,* Robson, 2002: 164). Green (2005: 34-5) stresses the similarities between a phenomenographic and a naturalistic enquiry, *eg,* inductive analysis. However, Green draws a boundary between the two through phenomenographic analysis focusing on the groups of interviewees, where a 'traditional' naturalistic enquiry focuses on the individual practical context. In this research enquiry this difference relates to looking across the field of practice – identifying the range of approaches – rather than developing a unifying model or presenting individual case studies. However, this research enquiry still qualifies as a naturalistic enquiry, because phenomenography is applied as an empirical data analysis method only, rather than defining the entire research strategy. The combination of a naturalistic enquiry and a practitioner-researcher (Robson, 2002) presents several methodological challenges for evaluating the research.

3.1.3.1 Evaluation criteria

The ease with which the naturalistic approach accommodates application of multiple methods is equalled in resulting complexity of evaluation. This includes validity and transparency within each method and in their combination, the researcher's position within the research enquiry, the status of the claims, and ethical considerations for a practice-led approach. Constructivist research generally borrows its evaluation criteria from the contrasting positivist traditions: reliability, replication, and validity. Parts of the social science field previously customised these criteria for qualitative research. Lincoln and Guba (1985: 294-301, here from Robson, 1993: 403-7), for example, proposed credibility, transferability, dependability, and confirmability. Finding that these modifications may increase the gap between positivist and constructivist research, current approaches instead adopt the original concepts with some modifications (Robson, 2002: 170; Bryman, 2004: 28-30). Consequently this research enquiry is based on *reliability, replication, and validity* as evaluation criteria.

3.1.3.2 Reliability, replication, and validity

Reliability and replication refers to the internal aspect of a methodology and each application of individual research methods. Validity refers to evaluating these aspects in relation to their external context.

Reliability refers to evaluating the instrument used to collect data – theoretical concepts and also the technical aids used, *eg,* audio equipment and transcription – and whether the results are repeatable (Robson, 2002: 176). The focus is here on ensuring that measures used for describing concepts, *eg,* units of analysis, are precise and consistent, in order that another researcher would yield similar units of analysis (Bryman, 2004: 28). In this research enquiry, the researcher represents the main research instrument. This poses a risk of subjectivity, *eg,* through the researcher-interviewee relationship, which may affect both data collection and analysis (Bryman, 2004: 284). However, the threat is limited within this research enquiry, compared to longer term studies, as the point of contact with contributing interviewees was limited to 1-2 hours' interview time. Reliability is also enhanced in this research enquiry through precisely defining the units of analysis, *ie,* the analysed graphic syntax aspects and theoretical concepts for identifying the rationale for information transformation.

Replication is directly linked to the above repeatability of results: would another researcher, applying the same units of analysis, produce similar results? Replication is acknowledged as being limited within social sciences, and addressed by clearly describing the applied procedures (Bryman, 2004: 28). In this thesis the procedures are both documented and secured by a systematic audit trail comprising the diagram collection, documentation of the pilot visual content analysis, logs of developing the interview guide, interview recordings – stored on mini discs – five interview transcripts, time coded indices of interviews, interview reports, and the matrices applied for data analysis.

Validity relates to the conclusions of the research. Bryman (2004: 28-29) outlines four types of validity; evaluated through the accuracy and completeness of data documented in the audit trail. In this research enquiry the types of validity relate to:

- *Measurement validity* - the appropriateness and precision of the theoretical and conceptual framework for identifying the design problem, current information transformation rationale, and alternatives.
- *Internal validity* - whether the interview guide, forming the link between the two research strands, enables valid integration of research findings

and analysis of plausible implications between models of design activity, theoretical implication in an ecological cycle network diagram, and occurrences of ambiguity in visual output.

- *External validity* - here relates to the nature of a 'meta-reflection-on-practice' and whether the results can be generalised beyond local contexts.
- *Ecological validity* - whether the findings are applicable to the everyday social setting, *ie,* meeting the practice-led aims of enhancing future practice. Ecological validity is particularly appropriate for evaluating the outcome of practice-led research.

Observing these measures of validity may reduce, rather than remove, the implications on the research, of the researcher's and interviewees' personal assumptions and biases (Robson, 2002: 172-176). Three additional means were applied in this research enquiry for increasing the validity (Denzin, 1980 here from Robson, 2002):

- Triangulation - using multiple methods,
- Peer debriefing - informal and formal disseminating to peers,
- Member checking - allowing interviewees to check interview recordings.

3.2 Visual content analysis

Visual content analysis is applied in the *first research strand* of this enquiry. This method enables systematic identification of graphic tactics in existing visual output. The coding scheme for the analysis – the combined units of analysis – serves two functions in this research enquiry. In addition to documenting the units of analysis, it is defined as representing the design problem space. As such the coding scheme reveals the general potential theoretical complication when designing an ecological cycle network diagram.

3.2.1 Systematic analysis of visuals

Content analysis emerged during the Second World War and was originally applied for quantifying written and spoken textual content (Rose, 2007: 61). Bell (2003: 13) defines the methods as:

> '…an empirical (obeservational) and objective procedure for quantifying recorded 'audio-visual' (including verbal) representation using reliable, explicitly defined categories.'.

Within research content analysis is mainly applied to analyse printed sources such as collected documents and texts or interview data in the form of transcripts. *Visual* content analysis is gaining methodological ground, *eg,* within media studies (Bell, 2003: 13), but remains a less common application than textual content analysis. The contrast in numbers of literature sources reflects this preference. Where there is a large number of books on textual content analysis (*eg,* Krippendorf, 1980; Rosengren, 1981), visual content analysis is described only in chapters within visual methodology books (*eg,* Rose, 2007; Bell, 2003). Rose (2007) presents a discussion aimed at wider audiences with one practical example. Bell (2003), aiming specifically at academic researchers, offers deeper description, discussion, and practical examples.

The application of visual content analysis in this research enquiry addresses two limitations of the method (Rose, 2007: 61): generally the focus on the composition of a visual output excludes consideration of both the production and reader contexts. This is addressed in this research enquiry, firstly, by the direct linkage between the two *research strands* aimed at revealing the production context. Secondly, by basing the units of analysis on graphic syntax aspects; relating to the reader processing. However, the general limitation still remains given the focus on identifying the potential effects that individual graphic tactics may have on the content proper message.

From a practical point of view, visual content analysis represents a series of prescribed activities with specific procedures (Bell, 2003; Rose, 2007). In this research enquiry the steps comprised: collection of ecological cycle network diagrams, pilot analysis, grouping of the data set, defining coding variables, and analysing the visual output.

3.2.2 Ecological cycle network diagram collection

A collection of ecological cycle network diagrams was established by searching through three textbook collections at educational university libraries:

- *Historical Textbook Collection, Institute of Education, London (1890-1970)* – 83 diagrams collected.
  Collection of British textbooks all educational levels and subject areas. The collection is particularly strong in examples from 1950-1970s.
- *Curriculum Resource Collection, Institute of Education, London (1970-present)* – 145 diagrams collected.
  The library's collection of contemporary British textbooks.
- *The Textbook Collection, Denmark's University of Learning, Copenhagen. (1910-present)* – 43 diagrams collected.
  Collection of Danish textbooks. All educational levels and subject areas.

609 textbooks[1] were searched for 'carbon-', 'nitrogen-', and 'water' cycle in the index. The pages which include visuals of the cycle subjects were photo copied. All these include a network diagram for each cycle described, resulting in 252 ecological cycle network diagrams, when instances of re-prints were removed. The collection of diagrams thereby revealed that the

1 Details of each book and keywords searched is recorded.

network diagram is an established paradigm for visually explaining the ecological cycle subjects for the 14-18 year age groups. Complementary photos were found in 55 of these books; illustrations in 16.

Practically, the collected material was scanned and stored electronically (as .tiff files) using Adobe Bridge CS3 as database software. During the analysis the defined units of analysis – *ie,* coding values – were applied as tags to the files; the search function allowing for displaying all diagrams with similar tags. The coding frequencies were collected in Microsoft Excell spread sheets. This leaves a careful and systematic paper trail of the procedure in both the pilot and final analyses.

3.2.3 Pilot visual content analysis

A substantial pilot visual content analysis was undertaken as part of this research enquiry, applying the framework of Engelhardt (2002) [section 2.3.2, p. 35] to all 252 collected ecological cycle diagrams. This pilot analysis helped develop the conceptual framework for this thesis by refining the theoretical focus. Part of the pilot analysis was focused on identifying the biological concepts represented by pictorial objects, plotting the content of pictorial labels in a table. This revealed the potential richness of analysing pictorial object labels and verbal syntax as graphic syntax aspects [sections 4.4.2, p. 131; 4.4.6, p. 150]. Identifying how these aspects may affect the information categorisation contributes expanded detail to existing graphic syntax theory. This part of the pilot analysis – extracting verbal annotations in tables – was also essential for identifying the general information types present in existing ecological cycle network diagrams [section 4.3.2.3, p. 113].

Furthermore, the pilot analysis helped define the indicators of graphic ineffectiveness applied in this thesis by exploring variation of each type within the data set [section 4.3.2.2, p. 110]. This revealed different types of implicit nodes and refined the detail of the indicator for inconsistency. The four indicators of graphic ineffectiveness in turn enabled identification of general ineffective graphic tactics, forming part of the coding scheme as units of analysis. Finally, the pilot analysis helped define a practical part of the content analysis – the formal, procedural step of grouping the visual material.

3.2.4 Grouping of data set based on pilot analysis

In the initial pilot analysis the data set of 252 ecological cycle network diagrams was grouped according to each cycle type. When instead arranging the entire data set chronologically, a close correlation between developments in printing techniques and the inclusion of different types of graphic objects was revealed:

- Early ecological cycle network diagrams are predominantly black and white, applying text, arrow, and possible rectangular shapes.
- Full illustration and pictorial objects do occur in earlier examples, but are rare until the 1950s.
- Examples from the 1970s show use of two colours, whereas those from the 1980s increasingly use four-colour, correlating to the introduction of lithography in the printing industry.
- Four-colour printing and pictorial objects are predominant in examples from the 1990s and the simpler text/arrow/shape combinations are rare post 2000.

Based on this gradual introduction of variables such as two- and four-colour palettes, I decided to divide the 252 ecological cycle network diagrams into sub-groups, which were based on the inclusion of basic graphic objects – text, shape, and pictorial objects – rather than the cycle type. This grouping enables detection of how the expanding graphic palette is utilised to categorise the information and relates directly to the indicator of graphic ineffectiveness for inconsistency[2] – *ie,* analysing how consistently the different attributes are applied. The re-organised groups critically exposed a relatively small representation of older Danish examples within the overall data set; three groups included only one or two Danish examples. This is due to the limited number of publishers on the Danish market and a high rate of straight re-prints of diagrams. This led to forming a sample of four current Danish examples (thereby excluding 39 Danish diagrams); leading to different functions and levels of representativeness for the two data sets.

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2 Three diagrams of the overall 252 include full illustration and arrows only, *ie*, no text graphic objects. These are noted here as including solely polysemic nodes and connectors, and excluded from analysis.

3.2.4.1 Function and representativeness of UK/Danish data set

For a valid visual content analysis it is essential to identify all the images relevant to the research question (Rose 2007: 61-63). The two data sets here represent different functions:

- The UK data set is seen as representative of ecological cycle network diagrams in UK science textbooks for 14-18 year age groups in the period 1930-2009. This is ensured by the wide year range, and all major publishers being represented within the collection. All the collected UK ecological cycle network diagrams are analysed in this research enquiry – a total of 205 – to identify the information categorisation in existing visual outputs, and the ineffective graphic tactics.

The resulting list of identified ineffective graphic tactics [table 5.1, p. 203] is then applied to analyse a sample of four Danish ecological cycle network diagrams. This additional analysis reveals whether the identified ineffective graphic tactics occur in the Danish visual output as well.

- The Danish sample of four diagrams is representative of ecological cycle network diagrams in current Danish science textbooks for 14-18 year age groups (2003-2008); one diagram from each publisher. The individual diagrams were chosen through a 'random' sampling strategy (Rose, 2007: 61-63).

3.2.5 Defining coding variables in coding scheme

In visual content analysis, coding equals 'attaching a set of descriptive labels (or 'categories') to the images' (Rose 2007: 64) *ie,* defining units of analysis and identifying the graphic objects which qualify as such. Precise definition of the units of analysis is here central for ensuring replicability (Rose 2007: 62). The smallest units of analysis are coding values, which are grouped under coding variables (Bell 2003: 15) [figure 3.1].

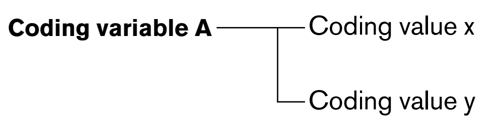


Figure 3.1: The units of analysis – coding variables consist of coding values.

Six coding variables are defined in this research enquiry, based on each of six graphic syntax aspects analysed: nodes and connector syntactic roles, arrow types, pictorial object labels, visual attributes, typographic attributes, verbal syntax. The coding values are defined in chapter four. The coding values represent individual graphic tactics, *ie,* the designer's choices of graphic objects to represent information types, and the organisation using the particular graphic syntax aspect. The defined coding variables and their sub-set of coding values combined form the coding scheme for the content analysis; a central element for ensuring validity:

> '"Validity" refers to the (apparently circular or tautological) concept of how well a system of analysis actually measures what it purports to measure. Valid inferences from a particular visual content analysis, given this definition, will reflect the degree of reliability in the coding procedures, the precision and clarity of definitions adopted and (a less obvious factor) the adequacy of the theoretical concepts on which the coding criteria are based.' (Bell, 2003: 26)

Rose (2007: 64) adds that coding variables should be 'enlightened'. This entails that the coding scheme provides a coherent and interesting decomposition as an overall analysis of the particular type of image. 'Enlightened' coding variables is an essential feature in this research enquiry, as the coding scheme is seen as representing the design problem space for the analysed graphic syntax aspects. In this research enquiry, the reliability of the coding scheme thereby relates, firstly, to the validity of the content analysis. Secondly, to the validity of integrating the research findings from the two *research strands* by defining the coding scheme as the design problem space. In addition to a precisely defined coding scheme, the precision when identifying graphic objects with a coding value – *ie,* analysing the images – is integral for a valid analysis.

3.2.5.1 Analysing visual output

Identifying which graphic objects qualify under a coding value needs to be executed unambiguously to ensure *reliability* and *replicability*. This may pose a challenge due to the subjective nature of visual analysis. The research focus of this research enquiry allows an interesting twist to replicability in the visual content analysis, consolidating that only one researcher undertook the analysis. One could say that this research enquiry turns replicability on its head, given that any instances of ambiguity in the diagrams are examples of ineffective graphic tactics. This research enquiry set out to count instances of such ambiguity enabled by the indicators of graphic ineffectiveness. For example, an unlabelled – *ie,* polysemic – pictorial object is identified by a coding value for 'unlabelled pictorial object', rather than interpreting the assumed meaning depicted. Ambiguous instances in diagrams which could cause differences in different researchers' coding, are, thereby, in this thesis affixed with coding values which are explicitly defined as ambiguous or general ineffective graphic tactics – in relation to the four types of graphic ineffectiveness.

One coding variable in this research enquiry is particularly critical in relation to reliable and replicable coding. The coding variable for identifying which information types are categorised in the syntactic roles of nodes and connectors [section 4.3.1, p. 105] relates directly to three of the four indicators of graphic ineffectiveness (implicit nodes, imprecise nodes, polysemy). This illustrates how this graphic syntax aspect needs particular attention when categorising information [section 5.5, p. 191], a finding which in turn informs the later recommendation for alternative graphic tactics [chapter 7]. The indicators of graphic ineffectiveness, thereby, enable identification of general ineffective graphic tactics – applying to network diagrams in general – which are included as coding values in the coding scheme. Application of the coding scheme, meanwhile, identifies additional ineffective graphic tactics which may arise from combinations of coding values.

3.2.5.2 Analysis outcome: frequencies of coding values

Visual content analysis results in a set of quantities that constitutes the frequencies of each coding value. Each coding value, in this research enquiry, represents a graphic tactic; some of which are general ineffective graphic tactics as identified by the coding scheme. Analysing the resulting frequencies of the coding values here allows for identifying additional ineffective graphic tactics which may arise from combinations of graphic tactics, specifically in an ecological cycle network diagram. Together the two sets of frequencies form a list of the general and cycle-specific ineffective graphic tactics found in the existing visual output [table 5.1, p. 203]. Each ineffective graphic tactic is elucidated throughout chapter 4 and 5, firstly, by demonstrating the potential effect on the content proper message in individual examples; secondly by highlighting the interrelated graphic tactics.

Within this research enquiry the coding scheme for the visual content analysis serves a conceptual function in addition to defining the units of analysis. The coding scheme here represents the design problem space investigated. As such the coding values indicate options for the designer within each graphic syntax aspect. The ineffective graphic tactics, meanwhile, indicate the limitations within this problem space, representing the internal constraints. Thereby, the visual content analysis identifies, firstly, the potential theoretical complication involved when categorising information in ecological cycle network diagrams using graphic syntax; secondly, the information categorisation in existing visual output. In addition to meeting the aim of the *first research strand*, this contributes a tool for practicing designers. Here the list of identified ineffective graphic tactics [table 5.1, p. 203] is demonstrated – using the Danish sample – as a check list for practitioners wishing to review visual output for ineffective graphic tactics.

Meanwhile, to identify the external constraints of the design problem, the ecological cycle network diagram is traced through its professional practice context using semi-structured interviews.

3.3 Semi-structured interviews

Semi-structured interviews are applied in the *second research strand* of this research enquiry, to identify the current information transformation rationale within the professional practice context. Here the interviewees are prompted to reflect on their practice and decision making in relation to choice points in the information transformation process. These reflections-on-practice are structured around the interview guide; ensuring a direct link to the *first research strand*.

3.3.1 'Reflection-on-practice'

Semi-structured interviews are often applied within multiple method studies to deepen the insight of other sets of findings (Robson, 2002: 272). This method allows for an open conversation structured around an interview guide, ensuring that the appropriate areas of research enquiry is addressed (Casell and Symon, 1999; Oppenheim, 2000: 70). In this research enquiry, the participants were asked to reflect on their practice, to identify the features they attended to, approaches, and rationale at each significant choice point. The resulting interviews represent individual 'reflections-on-practice' (Schön, 2006), which are then analysed and synthesised to form a 'meta-reflection-on-practice' (Schön, 2006; Cherry, 2005); *ie,* looking across the field.

The semi-structured interview, as a research method, potentially yields rich data through the interviewees' personal reflections. However, such data richness simultaneously poses a challenge for the reliability and validity of the collected data (Miles and Huberman, 1994: 10). Firstly, the researcher may impose biases and assumptions on the data collection process. Secondly, the data often include implicit and explicit personal biases and assumptions from the interviewees. These need teasing out of the data. Thirdly, the method separates the verbal information from other cues, *eg,* body language, and the transcription of recorded interview data further deletes the interviewee's pitch and tone of voice from the evidence. Lastly, as the data is further reduced, through analysis, the researcher's bias and interpretation may again influence the material.

In addition to these data-related issues on a practical level, the interview method is time-consuming, not just in preparation and actually interviewing, but also in analysing the data gathered. These limitations were addressed during the interview procedure in this research enquiry, guided by the formal features of the research method and informed by the theoretical framework of this research enquiry. The procedure here included three main steps:

- Defining the sampling strategy and identifying interviewees.
- Formulating research questions – based on pilot interviews.
- Conducting the interviews – including their documentation.

3.3.2 Sampling strategy

The general sampling strategy was formed through the literature review in this research enquiry. Editors, authors, designers, and illustrators were here identified as the participants of interest for this enquiry, due to their potential involvement in the decision-making [section 2.5.3.1, p. 58]. Defining the sampling strategy from the theoretical framework ensures transparency in the rationale for how the interviewees were selected (Bryman, 2004: 333), and appropriateness in relation to the research questions (Bryman, 2004: 334). The sampling strategy further allows the work presented in this thesis to go beyond Puphaiboon (2005) who was limited to interviewing designers only [section 2.5.3.1, p. 58].

The sampling strategy applied in this research enquiry also complements Evans *et al* (1987) whose lack of specific visual examples during their interviews resulted in collecting only general feedback. In contrast to this, Crilly (2005: 85) found that focusing on a particular product improved communication. The interviews conducted in this research enquiry are case-based, because the questions are focused on the ecological cycle network diagram. During each conducted interview, the interviewee's most recent – and older – textbooks were present and opened on the ecological cycle network diagram.

The combination of several participants and case-based interviews posed the challenge of finding publishers which could enable contact with a complete 'set' of interviewees. The participants in these 'sets' had to be all involved in the decision-making for the same ecological cycle network diagram in any of their current publications. These participants 'sets' were identified from the population overview (Bryman, 2004).

3.3.2.1 Population overview and sampling

Educational publishing is in this research enquiry defined as publishers specialising in producing learning material such as textbooks. Textbooks are distinct from popular science publications by being part of a series adhering to the national curriculum. Table 3.1 shows the population overview of publishers on the UK and Danish educational publishing market.

Publisher
UK - all UK publishers, except Folens, publish both secondary and A-level
Allan Philip Publishers, Deddington, Oxfordshire.
Cambridge University Press.
Folens, Dunstable, Beds.
Harper Collins Educational, London.
Heinemann Educational, Subsidiary of Pearson Education, Oxford
Hodder Headline, London.
Oxford University Press, Oxford.
Longman Publishing, Subsidiary of Pearson Education, Harlow, Essex.
Denmark
Gyldendal, Copenhagen. *Secondary/A-level material*
Alínea, Copenhagen. *Secondary material*
Nucleus, Århus. *A-level material*
Systime, Århus. *Secondary/A-level material*

Table 3.1: Population overview.

All publishers were contacted by phone and the sample formed based on who agreed to take part. This resulted in an interview sample comprising 19 interviewees; a sample size commonly expected in phenomenographic studies (Bowden, 2005: 17). Three interviews included two participants, resulting in 16 interviews. Two additional pilot interviews were conducted at a fourth UK publisher, with an editor and design manager.

Generally all editors were helpful 'gatekeepers' to other interviewees. The editors selected the 'set' of interviewees within each publisher and the publication/diagram discussed at each interview. Only two publishers – both Danish – are not represented with a full 'set' of interviewees; two were unavailable. At one publisher two interviews were scheduled, but another two, a commissioning and a copy editor agreed to take part on the day. The sample composition is discussed in detail in section 6.3 [p. 228]. The interviewees were sent an email with information about the research and their participation, and a consent form. The Research Ethics Committee at the University of the Arts London had approved all formal information.

3.3.3 Interview guide

The interview guide in this research enquiry served the crucial role of linking the two *research strands* [section 3.1.1.1, p. 68]. Generally the questions followed a standard structure (*eg,* Robson, 2002: 278; Bryman, 2004: 327), with three stages: *open* – brief notes on the company, their position, and background*, body* – the main questions, and *close* – inviting the interviewees to reflect on things they had mentioned and arranging details for feedback on findings. In this research enquiry, the interest was mainly on the interviewees' approaches to their practice, but factual questions (Robson, 2002: 272) are also included to determine the design process set up, *eg,* interviewees' formal roles in the information transformation. The link between the two *research strands* was enabled by centering the main questions around choice points in the brief development and translation processes, and the graphic syntax aspects analysed in the *first research strand*. For this main part of the interview guide the sequence of questions and their formulation was developed through the two pilot interviews.

3.3.3.1 Sequence of questions in interview guide

Two pilot interviews were conducted to practice my interviewing skills and test the initial interview guide. This guide was based on the pilot visual content analysis and included questions directly linked to Engelhardt's (2002) framework of graphic syntax. The first part, and majority, of this guide focused on the particular diagram and its elements, followed by questions about the general design process and sequence of events.

The first pilot interview revealed several flaws in the structure of questioning the diagram and then the process, as it resulted in the first part of the conversation being based on my assumptions about the publishing process. Based on this experience, the structure was changed; the first part now relating to 'what happens' and 'who's involved'; the second part relating to the evolution of the diagram and decisions in the brief development and translations processes. Triangulation (Bryman, 2004; Robson, 2002) was employed within the individual interview by querying about individual graphic syntax aspects at different developmental and evaluational stages. An additional interview triangulation was applied by presenting all interviewees with the same example of one diagram and asking them to freely evaluate it. To avoid language preferential treatment, a Spanish diagram was chosen [appendix 1].

Here are listed the ten main question themes [appendix 2 presents the full interview guide]:

1. Demographic information.
2. Describe design process for double page spread and visuals within it.
3. Format of the artwork brief, its development, and evaluation
4. Reference material provided with brief
5. Purpose of each visual element – photos, graphs, diagrams – in the double page spread
6. Evaluation of first draft of a diagram
7. Evaluation of final diagram
8. Reflection on own work process
9. Spanish diagram: how would you evaluate if received for use in a book?

This structure was tested in a second pilot interview, which also included developments in the phrasing of interview questions.

3.3.3.2 Formulating questions in interview guide

In the interview guide developed for the first pilot interview, some questions were phrased broadly, *eg,* 'how was the type and structure of each visual element on the page chosen?', and a list of prompts included as keywords.

This lack of detail in the phrasing caused me to improvise when expanding the prompts; resulting in too open a conversation, loss of structure, and schedule. Departure from the guide resulted in less rigour in questioning, *eg,* by asking leading questions. Based on this, the guide was edited to include a list of ten main questions, followed by prompts written out as full sentences.

In contrast to the broad questions, the initial guide also included questions with direct reference to the visual content analysis and Engelhardt's framework (2002). This aimed at providing a tight link between the *research strands*. However, the direct reference resulted in very academic terminology such as questioning how the 'syntactic roles' were considered. The tight terminological linking was impractical as the short span of the interview offered less possibility to establish joint definitions between interviewer and interviewee. This experience, thereby, exposed a gap between adopting a precise model of academic terminology and its usefulness when communicating with practitioners from the publishing context.

A solution here could be to use the descriptions applied when defining the academic terms. However, to do so, the researcher risks imposing the particular theoretical viewpoint on the interviewee, *ie,* here specific theories about graphic syntax. This may alienate the interviewee and impose biases on the collected data. The development of interview questions, thereby, exposed a challenge – for the academic field of information design – to increase the unifying aspects of academic frameworks and bridging them to vocabularies of professional practice. Simultaneously, it challenges the field of practice to increase the precision in their chosen terminology.

For this research enquiry, the academic terminology was instead 'translated' into a broader practice-led vocabulary. For example, instead of asking how an interviewee considers the information categorisation using syntactic roles, the question was phrased as, 'if we look at the visual objects within the diagram, what would you say is the purpose of each type?', and 'How do you consider the information applied to each type of object in a diagram, for example what is applied to the arrows and what is shown pictorially?'. A second pilot interview here confirmed the assumed improvements by yielding higher quality data from the edited questions.

The 'de-academisation' of the interview questions has two implications for the methodology of this research enquiry. Firstly, the broadening of the terms used to describe concepts were now open to personal interpretation by the interviewee affecting the reliability of the data. Secondly, the 'translation' affects the precision in the link between the two *research strands*; *ie,* the internal validity of the research enquiry. However, given that the essence of the academic definitions is preserved, the validity of integrating the two sets of research findings remains intact.

3.3.4 Conducting and documenting interviews

The interviews were held in the interviewee's office or authors' home and recorded on mini-discs to maximise transparency as part of the data trail (Bryman, 2004: 289). Each 'set' of interviewees was questioned about their most recent published science textbook, with an ecological cycle network diagram on which they co-operated. This book was present during the interview and initiated conversation. In addition to this specific case, most interviewees made reference to material they were currently working on. These comments were included in the data analysis as some of these current processes build directly on experiences from the previous ones.

The 16 interviews conducted lasted between 45 minutes and 2 hours, yielding between 7,000-12,000 words each. Five of the 16 interviews were transcribed in full. From these transcripts, a matrix structure was developed for the data analysis [section 3.4.3.2, p. 93]. This documentation strategy was chosen based on the high level of pre-structuring and information seeking research approach [section 3.1.1.2, p. 69]. All interviewees were sent a copy of the recordings or transcripts. The following section discusses how phenomenographic analysis was applied to analyse this mountain of data.

3.4 Interview data analysis: phenomenography

Phenomenogaphy is an empirical data analysis method, applied in this research enquiry to identify the features attended to, the approaches, and the rationale at choice points in the information transformation process. This forms a 'meta-reflection-on-practice' (Schön, 2006; Cherry, 2005), a composite of the individual reflections-on-practice provided by each interviewee. In turn this represents the current information transformation rationale.

3.4.1 Identifying variation in approaches to practice

Phenomenography was selected for this research enquiry as the method enables analysis of an expansive design situation from a range of perspectives (Adams *et al,* 2009). This method studies variation of experiences – here approaches to practice – as an object. Phenomenographic research is currently found within the design field, *eg,* in engineering education where it has been applied to investigate variation in experiencing sustainable design (Mann *et al,* 2007) or cross-disciplinarity (Daly *et al,* 2008). In this research enquiry, the method was applied solely as a descriptive and empirical analysis method enabling identification of variation and similarity in the interviewees' approaches to information transformation.

Phenomenography originates from work in the educational research field (*eg,* Marton, 1981; Dahlgren 1984). The original applications resulted in theories about deep- and surface-approaches to learning among university students (Marton and Säljö, 1976). The empirical method has later developed into a theory, 'variation theory' (Pang, 2003; Marton and Pong, 2005: 336) which describes the structural aspects of identified experiences. The relative youth of the method has resulted in criticism, *eg,* that discussions within the field focus on the broader aims and outcome of the method, rather than rigorous procedure details and description (Ashworth and Lucas, 2000: 296). However, a steady development during the past decade has yielded two methodology-focused texts (Bowden and Green, 2002; Bowden and Walsh, 2005), and increasingly critical and detailed description.

3.4.1.1 Object of study within phenomenography

A phenomenographic study gathers descriptions of how a person experiences and deals with a particular aspect of their world. In terms of ontology – the study of being and how we know what we know – the approach is based on a non-dualistic view of cognition. In this view knowledge is created through peoples' relations to each other and their relation to the world. This view sits between the objective constructivist view – positivism – and the subjective, social constructivist positions (Marton, 1981). In the former human behaviour is seen as a result of internal mental acts, *ie,* independently of human interpretation. In the latter it is seen as purely internal construct, independent of the external world (Marton and Booth, 1997: 13; Bowden, 2005: 12). Figure 3.2 visually summarises how phenomenography is applied to study the relations between the subjects – here participants – and the aspect of the world.

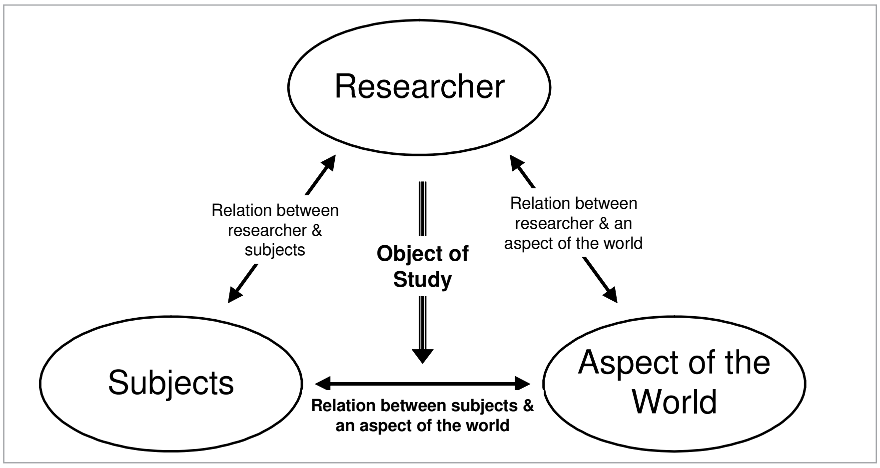


Figure 3.2: The research focus of phenomenography (Marton and Booth, 1997: 6)

The analysis in this research enquiry follows the non-dualist view on cognition. The findings thereby represent a 'second-order' perspective (Marton, 1981) on the approaches to information transformation; developed through the individual snap-shots provided by the interviewees' 'reflections-on-practice' (Schön, 2006). This affects the validity of the collected data which is defined as reflecting the relation between the interviewees and their practice at the time of the interview, rather than at the time of the actual design process – which took place between 2-6 years earlier.

These limitations are somewhat consolidated by all interviewees currently being active practitioners – as editors, authors, illustrators, or designers – and all included comparison to current practice when reflecting on the discussed ecological cycle network diagram examples. Meanwhile, the relationship between the researcher, interviewee, and the aspect investigated requires the researcher to 'bracket' own biases and assumptions about the investigated aspect and the interviewees during the phenomenographic analysis. Researcher bracketing is here documented through the systematic data trail of the data analysis and research outcomes.

3.4.2 Phenomenographic outcomes

A phenomenographic analysis yields two outcomes (Åkerlind *et al,* 2005). First are developed descriptions of variation within the data set, termed 'categories of description'. The 'categories of description' are then organised hierarchically from more comprehensive to less comprehensive. This map of variation forms the 'outcome space'. A phenomenographic 'outcome space', thereby, maps different variations and their overlaps, rather than detailed individual approaches or evaluation of the categories. The method yields an abstract and descriptive map; a composite of the interviewees' view points (Mann *et al,* 2007).

In this research enquiry the 'outcome space' is pre-structured around the identified choice points and in relation to the brief development and translation process stages, rather than hierarchically. The 'categories of description' are here the features attended to at each choice point, and the variation in approaches. The outcome of the interview data analysis thereby represents a snap shot of the current information transformation rationale. It is a snap shot of the variation in approaches found within the data set, rather than an exhaustive picture. An individual interviewee should here recognise the map as a unity – *ie,* the overall features in the rationale – rather than identifying their individual process (Bowden, 2005).

3.4.3 Phenomenographic analysis: practical application

The limited application of phenomenography in this research enquiry – for data analysis only – diverts from the conventional application by pre-structuring the outcome space. This reduced the complexity of the practical procedure which was structured around three main activities when analysing data from qualitative interviews (Miles and Huberman, 1994: 10-12): 1) data reduction, 2) data display, 3) conclusion drawing and verification.

3.4.3.1 Data reduction and analysis

For developmental phenomenography Bowden (2005: 19) strongly recommends collecting all data before starting the analysis, to avoid influencing the data by mentioning any identified categories in proceeding interviews. Phenomenographic analysis thereby parts with the emergent and iterative data analysis procedure of, *eg,* grounded theory (*eg,* Miles and Huberman, 1994: 50). Phenomenographic analysis is also distinct from analytical induction (Bryman, 2004: 400) through the mapping of variation rather than seeking a unified explanation.

In this research enquiry the collected data was reduced through process logs, interview reports, summaries, and detailed time-labelled indices of each interview, with keywords, and key quotes of each answer given by the interviewees. This approach to data reduction was evaluated by checking against the five transcripts. The data analysis follows Bowden's instructions about phenomenographic analysis sequence, but departs from a full phenomenographic analysis structure by applying template analysis, selected from Robson's (2002: 58) four approaches to data analysis:

- *quasi-statistical* - eg, visual content analysis,
- *template* - codes derived from theory and research questions, forming the 'template', and often analysed through matrices,
- *editing* - the grounded theory approach in which codes are formed from the data,
- *immersion* - the most open analysis approach, non-systematic and subjective.

Matrices were used as visual displays for this template analysis. These were explanatory – *ie,* information seeking – rather than exploratory matrices (Miles and Huberman, 1994: 240).

3.4.3.2 Data displays: matrices

The matrices used for reducing and organising the interview data in this research enquiry were well-ordered (Miles and Huberman, 1994: 240) and pre-structured according to the interview guide. These included one time and role-ordered matrix for each publisher (Robson, 2002: 482) which included the interviewees' descriptions of their working process and the sequence of events. Summarising the answers from each interviewee in the individual 'sets' of participants allowed for analysis of variation between different roles within an individual publisher, as well as between publishers. This in turn enabled identification of the formal sequence of decisions and the participants who are formally or informally involved in the decision-making.

Practically, the first analysis step included the insertion of 'thick description' (Miles and Huberman, 1994: 241) quotes into the matrix cells, *ie,* including entire answers and time codes, rather than keywords or summaries. The next analysis step entailed identification of variations and similarity in approaches at each choice point. This was done by manually coding – *ie,* marking with highlighter pen and notes on print outs – the varying approaches. These were identified across the cells as many interviewees provided broad reflection on individual questions, addressing several choice points in one answer. Consequently the matrices were re-read, 'up and down' eight to ten times, in line with phenomenographic procedure advice (*eg,* Bowden, 2005).

Similar to transcripts in phenomenography, the matrices developed for this thesis are seen as independent of the person interviewed (Cherry, 2005: 59). Instead, they represent 'snap-shots' (Cherry, 2005: 60) of the interviewees' reflection-on-practice. The data is therefore taken at face value rather than interpreting the features such as assumptions and biases *etc*.

3.4.3.3 Conclusion drawing and verification

The final data analysis activity involves the drawing of valid conclusions from the similarity and variation in approaches identified through analysing the interview data set. Phenomenographic analysis here faces the same challenges for replicability as other qualitative research approaches [section 3.1.3.1, p. 71]. Marton (1986: 35) argues that the identified categories exist within a 'context of discovery' – the researcher's own second-order construction [section 3.4.1.1, p. 90]. Based on this, some phenomenographers argue for evaluating 'inter-judge reliability' (Sandberg, 1997: 205) ensuring that peers recognise the categories of description. In contrast to this, replicability and reliability in this thesis are grounded in the pre-defined units of analysis – the choice points. This theoretical anchoring of the outcome space enhances the researcher bracketing. Due to this strategy, this research enquiry excluded group analysis control measure which checks for inter-coder consistency (Bowden, 2005: 15).

The nature of phenomenography – only identifying and categorising the essence of a subject, in favour of individual paths – is a point of criticism from a grounded theory and broader naturalistic research enquiry perspective (Green, 2005; Bowden, 2000). Cherry (2005) addresses this issue from an action research context arguing that phenomenography enables a reflection on practice through stimulating 'critical thinking about the deep assumptions, which drive thinking, feeling, and action' (Cherry 2005: 58). Mapping the overall variation here enables detachment from local issues such as politics and personal relations. A phenomenographic data analysis is, thereby, highly appropriate for practice-led research, which ultimately seeks to improve a field of practice (Woolley 2000b) [section 1.5.2, p. 17]. Furthermore, the 'meta-reflection-on-practice' (Schön 2006; Cherry 2005) contributed by this thesis represents a foundation which may be further developed into detailed models of information transformation processes.

Summary

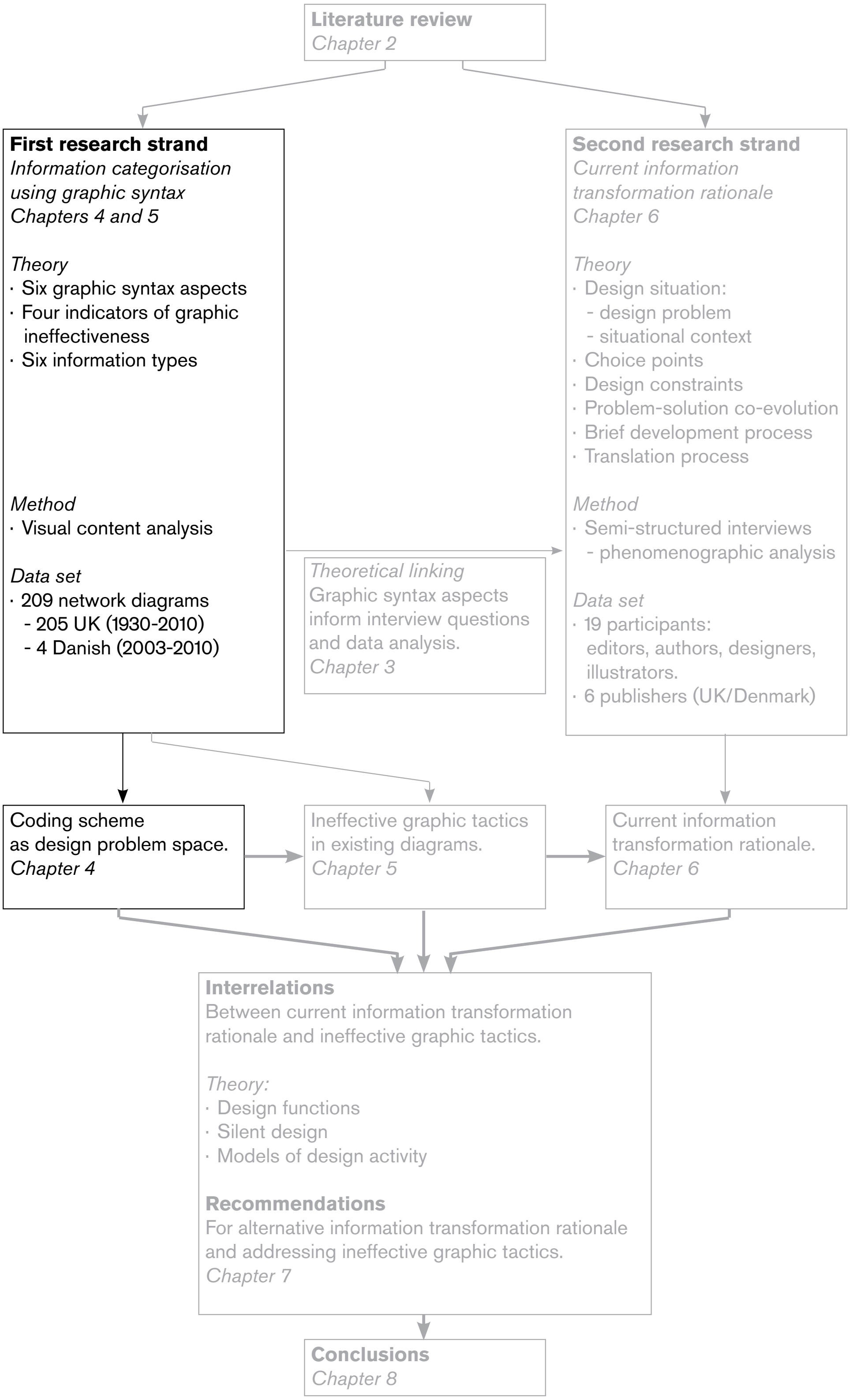
The research strategy developed to meet the aims of this research enquiry combines multiple methods, applied in two *research strands*. A theoretical link is provided by the two strands through the interview guide which enables the integration of research findings. Together this forms a practice-led naturalistic research enquiry.

Visual content analysis of 205 UK and four Danish ecological cycle network diagrams, was outlined as applied in the *first research strand*. This method enabled a systematic analysis of graphic tactics in existing visual output.

The pilot content analysis was discussed, including its role in grouping the data set and developing the coding scheme. Different functions of the coding scheme for the visual content analysis were discussed, firstly, as defining the units of analysis – coding variables and their values – and secondly, as representing the design problem space. It was outlined how the frequencies of the coding values identify general and cycle specific ineffective graphic tactics in the data set. These ineffective graphic tactics were defined as the potential theoretical complication of an ecological cycle network diagram.

16 semi-structured interviews of 19 authors, editors, designers, and illustrators, at three publishers in the UK and three in Denmark were conducted for the *second research strand*. The interview guide was developed through pilot interviews and informed by the analysed graphic syntax aspects. This interview data set is analysed using phenomenographic data analysis method, as well as thick description matrices; yielding a 'meta-reflecton-on-practice'.

4 Visual content analysis



Literature review
Chapter 2
First research strand
Information categorisation using graphic syntax
Chapters 4 and 5
Theory
· Six graphic syntax aspects
· Four indicators of graphic ineffectiveness
· Six information types
Method
· Visual content analysis
Data set
· 209 network diagrams
- 205 UK (1930-2010)
- 4 Danish (2003-2010)
Second research strand
Current information transformation rationale
Chapter 6
Theory
· Design situation:
- design problem
- situational context
· Choice points
· Design constraints
· Problem-solution co-evolution
· Brief development process
· Translation process
Method
· Semi-structured interviews
- phenomenographic analysis
Data set
· 19 participants:
editors, authors, designers, illustrators.
· 6 publishers (UK/Denmark)
Theoretical linking
Graphic syntax aspects inform interview questions and data analysis.
Chapter 3
Coding scheme as design problem space.
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Ineffective graphic tactics in existing diagrams.
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Between current information transformation rationale and ineffective graphic tactics.
Theory:
· Design functions
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Contents

4 Visual content analysis

4.1 Introduction

Visual content analysis was chosen in the *first research strand* to trace the visual output through its theoretical context and identify how information in existing visual output is categorised using graphic syntax. This analysis identifies the information categorisation in existing examples and reveals the general theoretical complication – in relation to graphic syntax – when transforming information into an ecological cycle network diagram.

4.1.1 Potential theoretical complication in information categorisation

The visual content analysis in this research enquiry is guided by questioning which potential theoretical complications are involved when categorising information in an ecological cycle network diagram, and how information is categorised in existing visual output. This investigation is facilitated by the coding scheme for the visual content analysis which serves both a practical and a conceptual research function in this research enquiry. Practically, the coding scheme documents the defined units of analysis, *ie,* the coding variables and their sub-sets of coding values. The coding scheme thereby enables reliable and replicable identification of graphic objects which qualify within each coding value. This in turn facilitates the research outcome, *ie,* identifying the information categorisation in existing visual output.

In this research enquiry, the coding scheme serves an additional conceptual function of representing the design problem space investigated. This conceptual function is enabled by the theoretical framework and the components which form the coding scheme: the analysed graphic syntax aspects, indicators of graphic ineffectiveness and information types in ecological cycle network diagrams. Each coding value – *ie,* the smallest units of analysis - here represents an individual graphic tactic, within the respective graphic syntax aspect. Taking the indicators of graphic ineffectiveness into account when defining the coding values, here facilitates definition of general ineffective graphic tactics – applying to network diagrams in general – based on existing graphic syntax theory. Thereby the coding scheme reveals general theoretical complication when categorising information in a network diagram. These represent general internal constraints of the design problem space.

Applying the coding scheme in analysis identifies the frequencies of the coding values – *ie,* graphic tactics – and thereby the information categorisation in existing visual output. The frequencies of coding values here allow for identifying additional ineffective graphic tactics. These relate to ambiguities arising from different combinations of coding values and are ecological cycle specific. These additional ineffective graphic tactics and the general ones together reveal the potential theoretical complication when categorising information in an ecological cycle network diagram – hence cycle specific and general internal constraints of the design problem space.

The identification of internal constraints is essential for this research enquiry and the later integration of the research findings. Knowledge of the potential theoretical complication here reveals whether the occurrences of any ineffective graphic tactics - hence ambiguities - are affected by inherent complication in the design problem space, in addition to the external constraints, *ie*, the features in the professional practice setting.

To present the coding scheme this chapter is structured in the following sections. The data sets are described next [section 4.2, p. 102], followed by the conceptual framework for the coding scheme [section 4.3, p. 105], and then each of the six coding variables [section 4.4, p. 115]. Finally, the coding scheme is discussed as design problem space [section 4.5, p. 155].

4.2 Data sets

The ecological cycle network diagrams collected for this research enquiry were separated into a UK and Danish data set, during the pilot visual content analysis. The UK data set is used for the main analysis and is further grouped according to the inclusion of graphic objects in the diagrams. The findings from the UK data set is then used to identify whether ineffective graphic tactics occur within the Danish data set.

4.2.1 Functions of UK and Danish data sets

The visual data analysed in this research enquiry comprises 205 ecological cycle network diagrams from UK science textbooks (1930-2009) [appendix 3] and four from science textbooks currently on the Danish market, as previously described [section 3.2.4, p. 77]. The two data sets serve different functions. The UK part of the data set is analysed to identify the general information categorisation, *ie, 'neutral'* and *ineffective* graphic tactics, and those arising from combinations of coding values. The combined list of general and cycle specific ineffective graphic tactics are then checked against the Danish sample, to review whether the ineffective graphic tactics also occur in the visual output from this country. These data sets and their functions were defined during the pilot analysis [section 3.2.3, p. 76], as was the grouping of the diagrams in the UK data set.

4.2.1.1 Description of UK diagram groups

The 205 UK ecological cycle network diagrams are separated into six analysis groups (G1-G6) according to their inclusion of different types of basic graphic objects: pictorial, shape, and text (Engelhardt, 2002: 119-120). The first four of these six analysis groups are based on text and arrows as the basic grouping variables, and each group distinct by the inclusion of other types of objects. Containers here refer to shapes, such as rectangles that 'contain' a node (Engelhardt, 2002: 44):

- G1: Text and arrow [figure 4.1]
- G2: Text, arrow, and container [figure 4.2]
- G3: Text, arrow, and pictorial object [figure 4.3]
- G4: Text, arrow, container, and pictorial object [figure 4.4]

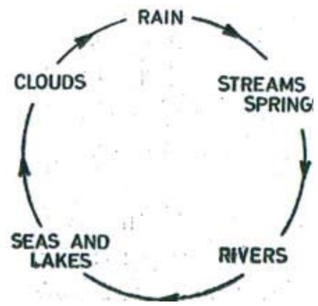

Figure 4.1: Diagram no 046

Graphic syntax aspect highlighted
Group 1: Text and arrow

The water cycle
From: Atkinson (1964: 56)

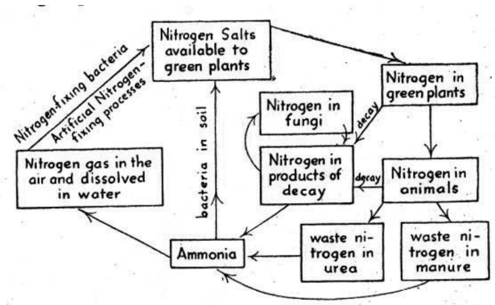

Figure 4.2: Diagram no 055

Graphic syntax aspect highlighted
Group 2: Text, arrow and container

The nitrogen cycle
From: Andreade (1935: 143)

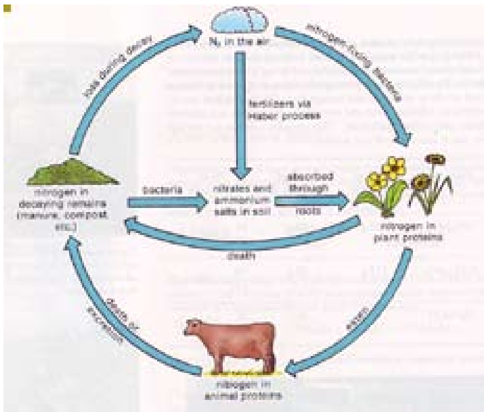

Figure 4.3: Diagram no 119

Graphic syntax aspect highlighted
Group 3: Text, arrow, and pictorial object

The nitrogen cycle
From: Hill (1993: 19)

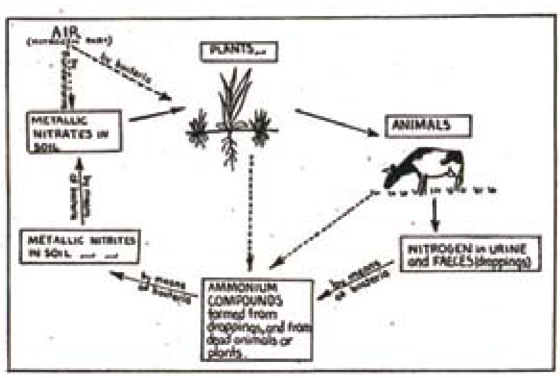

Figure 4.4: Diagram no 125

Graphic syntax aspect highlighted
Group 4: Text, arrow, pictorial object, and container shape

The nitrogen cycle
From: Smith (1948: 192)

Two additional diagram groups are needed to accommodate diagrams which make use of full pictorial illustration, rather than separate pictorial objects. These two groups are based on Engelhardt's (2002) definitions of graphic spaces in diagrams. Engelhardt (2002: 57) defines pictorial illustrations as 'integral metric spaces'. These are graphic spaces in which the spatial relations can be interpreted in all directions, *ie,* diagonally, horizontally, and vertically[1]. The pilot analysis included the graphic space as a coding variable, but this is excluded from the final analysis to concentrate only on six selected graphic syntax aspects [see section 4.3.2.1, p. 107]. The integral space definition is thereby used solely to define two groups of diagrams which include full illustration:

1 As opposed to a 'metric axis', *eg,* a time line; a 'composite metric space', *eg,* an x and y axis; or an 'unstructured direction' in which the spatial dimensions do not carry specific meaning (2002: 57).

- G5: Text, arrow, and integral metric space [figure 4.5]
- G6: Text, arrow, integral metric space, and container [figure 4.6]

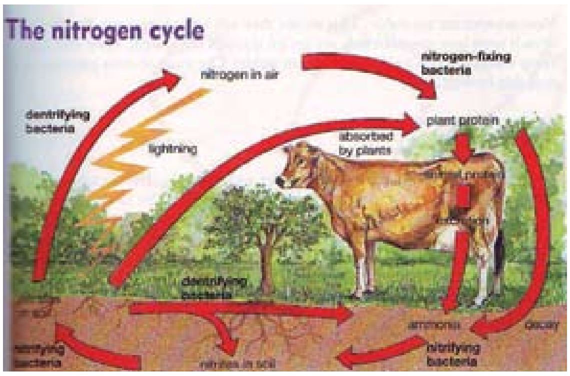

Figure 4.5: Diagram no 180

Graphic syntax aspect highlighted
Group 5: Text, arrow, and integral metric space

The nitrogen cycle
From: Sears and Taylor (1994: 21)

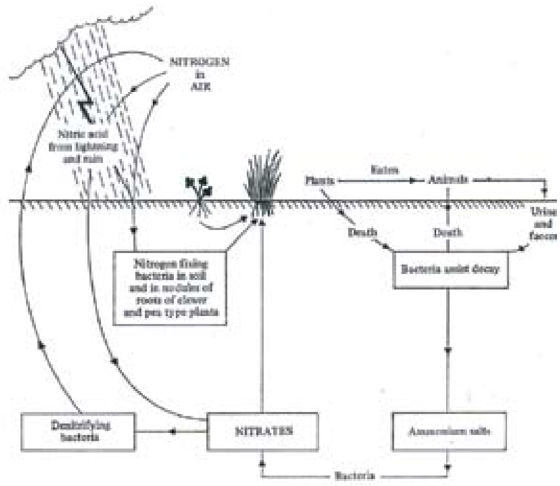

Figure 4.6: Diagram no 197

Graphic syntax aspect highlighted
Group 6: Text, arrow, integral metric space, and container

The carbon cycle
From: Chillingworth (1971: 84)

Figure 4.7 presents the UK data set as distributed in the six diagram groups and according to types of ecological cycles[2]. The frequency of cycle types in a diagram group is mentioned where appropriate throughout chapter 5.

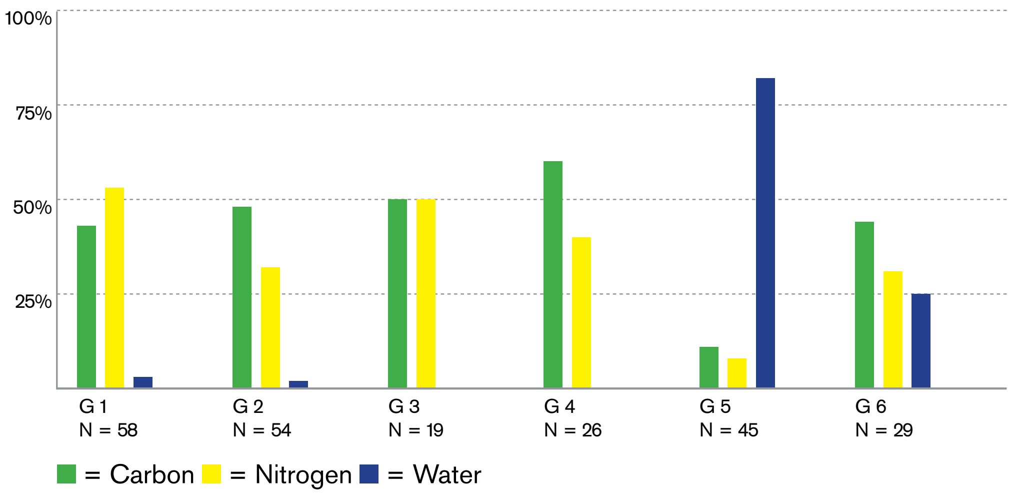

Figure 4.7: Percentage cycle types in each diagram group·

2 This reveals an initial analysis finding, that 'integral metric spaces' are a common preference for network diagrams of water cycles. This preference may be explained by the nature of the content proper in the water cycle which includes a scenario of mountain areas, water running downhill in rivers, and the sea.

4.3 Coding scheme

The coding scheme forms the core of a visual content analysis. The practical function of the coding scheme is to document the defined coding variables and their values – the smallest units of analysis. The coding values in this coding scheme are defined by synthesising from the analysed graphic syntax aspects, indicators of graphic ineffectiveness, and general information types. This enables definition of coding values which represents general *'neutral'* or *ineffective* graphic tactics.

4.3.1 Identifying categories of information in network diagrams

The coding scheme in this research enquiry was formed to identify how the information represented in an ecological cycle network diagram is categorised through graphic objects and their graphic relations. A category of information is here a nominal, ordinal or quantitative grouping of graphic objects created within a diagram (Bertin, 1983; 2000/01), hence groupings of the represented content proper. Nominal refers to categorising information by visual association or disassociation; ordinal to creating a visual hierarchy, and quantitative to creating visual groups based on related numerical information. Analysing such categories of information here reveals the relationship between 'what is shown' and the nature of the content proper, and whether ambiguity may potentially result from the composition. Furthermore, this analysis reveals the potential theoretical complication when representing and categorising information through graphic objects and their graphic relations in a network diagram.

Engelhardt (2002: 30) describes how graphic objects may be involved in two overall types of graphic relations:

- 'Object-to-space relations' – spatial relations between objects and the graphic space in which they are presented, and
- 'Object-to-object relations' – which are either:
  - spatial relations between one or more graphic objects, or
  - 'attribute-based relations' between the colour, texture, size, or brightness of the objects.

The coding scheme in this research enquiry is based on analysing 'object-to-object relations'. The coding variables centre on analysing nodes and connectors, which are the defining syntactic roles in network diagrams.

4.3.1.1 Syntactic roles in network diagrams

In Engelhardt's framework, network diagrams belong in a 'linking by a connector' category within spatial 'object-to-object relations' [figure 4.8].

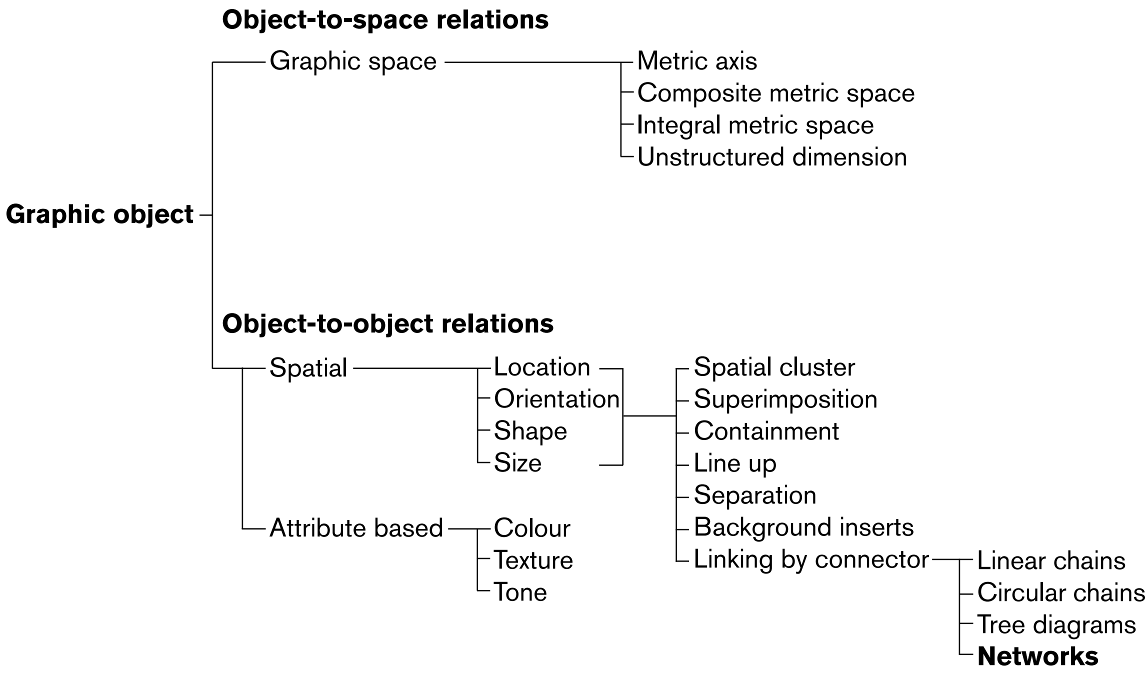

Figure 4.8: Location of network diagram in Engelhardt's graphic syntax framework.

'Linking' is thereby the defining syntactic feature, here facilitated by the 'connector':

> 'A connector is a graphic object in the shape of an arrow, band, or line that is anchored to two other graphic objects (nodes), connecting them… connectors may be visually directed (arrows) or undirected (lines or bars).' (Engelhardt, 2002: 40)

Based on this, a network diagram is defined in this thesis as a set of nodes and visually directed connectors, in which two or more nodes are linked in an open or closed loop. This definition contributes to a refinement of the detail in Engelhardt's framework. The definition was developed by including Engelhardt's four sub-categories of linking – 'linear chains', 'circular chains', 'tree diagrams', and 'networks' [figure 4.8] – as coding variables in the pilot analysis. This revealed ambiguity in Engelhardt's definition, which is discussed in appendix 4 to provide context for the definition applied here.

In relation to information categorisation, the two syntactic roles create two fundamental categories of information: content proper elements that are 'connected' – nodes – and those that 'connect' – connectors (Richards, 1984; Engelhardt, 2002). These two syntactic roles in turn represent the fundamental relationship between biological concepts in the ecological cycles when shown in a network diagram. If more than one information type is included in the set of nodes or connectors, *eg,* some elements are organisms, some are matter, the designer has several options for visually grouping the categories of information. To analyse information categories within and between nodes and connectors – and how ambiguity may occur – the coding scheme in this research enquiry is synthesised from different theoretical components.

4.3.2 Theoretical components of coding scheme

The coding scheme in this research enquiry is formed from three components: graphic syntax aspects, indicators of graphic ineffectiveness, and general information types in ecological cycle network diagrams. These components enable identification of the information that is represented in a diagram, how it is categorised using graphic syntax, and whether ambiguity may potentially result from the information categorisation within and between nodes and connectors. The graphic syntax aspects here form the coding variables, whilst the indicators of graphic ineffectiveness and the information types inform the definition of coding values – the smallest units of analysis – within each coding variable.

4.3.2.1 Graphic syntax aspects

The coding scheme in this research enquiry comprises six coding variables, based on six graphic syntax aspects. These were selected to ensure a coherent and interesting decomposition of information categorisation in network diagrams, *ie,* an 'enlightened' coding scheme (Rose, 2007: 64) [section 3.2.5, p. 78]. At the heart of this coding scheme lies the syntactic roles of nodes and connectors which form the first coding variable. The remaining five coding variables are then defined, to analyse how categories of information are created within and between the nodes and connectors. These graphic syntax aspects comprise pictorial objects, arrow types, visual attributes, typographic attributes, and verbal syntax:

- **Nodes and connectors**
  This coding variable identifies which information is represented in visually similar nodes and connectors, and, in turn, the information types that are represented as connected or connecting in the data set. When identifying visual similarity, the five other graphic syntax aspects are here taken into account [section 4.4.1, p. 115].

- **Pictorial objects**
  Text labels may be applied to pictorial objects to specify the information represented by the graphic object. Analysing pictorial object labels here reveals an additional set of graphic relationships – and options for creating additional information categories – based on the relationship between what is explained in the label and what is shown in the picture, *ie,* the text-image relationship (Engelhardt, 2002; Schriver, 1997). This coding variable also identifies sub-categories of information created within pictorial nodes [section 4.4.2, p. 131].

- **Arrow types**
  The information included in an arrow label affects the type of the arrow which may be either a movement arrow or conceptual link (Engelhardt, 2002). In turn this coding variable identifies two sub-categories within the connecting elements: chemical transfers and chemical transformations [section 4.4.3, p. 136].

- **Visual attributes**
  Coding variables 4 and 5 relate to Engelhardt's 'attribute-based' graphic relations [section 4.3.1, p. 105]. These identify how different categories of information are created – within and between nodes and connectors – by applying visual or typographic attributes to graphic objects. Coding variable 4 identifies how visual attributes – colour, shape, size, and texture

– are applied to arrows and container objects [section 4.4.4, p. 139].

- **Typographic attributes**
  Coding variable 5 identifies whether text objects are associated or disassociated through their typographic attributes (Twyman, 1982; Richards, 1984; Schriver, 1997) [section 4.4.5, p. 147].

- **Verbal syntax**
  The final coding variable is a direct result of the pilot analysis in this research enquiry and originally inspired by Stylianidou *et al* (2002). This coding variable is applied to identify how the verbal syntax of text objects may create categories of information within and between nodes and connectors [section 4.4.6, p. 150].

The six coding variables are summarised visually in figure 4.9:

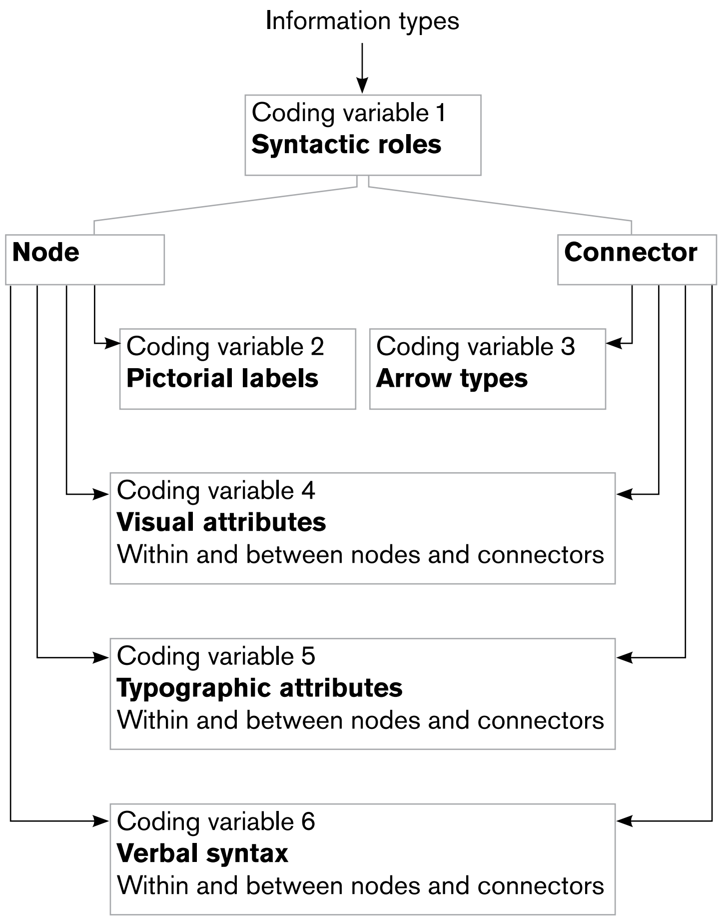

Figure 4.9: Conceptual framework of coding scheme.

4.3.2.2 Indicators of graphic ineffectiveness

An indicator of graphic ineffectiveness is here a theoretical measure for identifying ineffective graphic tactics within each graphic syntax aspect, *ie,* instances of graphic composition where the information categorisation may result in ambiguity about the content proper. Ineffective graphic tactics here reveal the potential theoretical complication when designing a network diagram.

Four indicators of graphic ineffectiveness were defined for this thesis. The two first indicators of graphic ineffectiveness relate to coding variable 1 – node and connector syntactic roles – and how to identify information in the syntactic role of a node. Identifying graphic objects serving as nodes posed several challenges in the pilot analysis. This was caused, firstly, by ambiguity in existing theory when describing the physical characteristics of a node [section 4.4.1, p. 115]. Secondly, the pilot analysis unravelled several instances in the analysed data set, where the nodal role of graphic objects are implicit or imprecise. Implicit and imprecise nodal points relate to Gestalt theory and the laws of good continuation, and spatial proximity (Koffka, 1935) . These two indicators of graphic ineffectiveness are outlined here and defined in detail as individual coding values in section 4.4.1 [p. 115].

Implicit nodes

Implicit nodes occur when the physical shape or spatial positioning of arrows, in relation to other objects, suggest an implicit connected element. This may create ambiguity about the related 'hidden' content proper element.

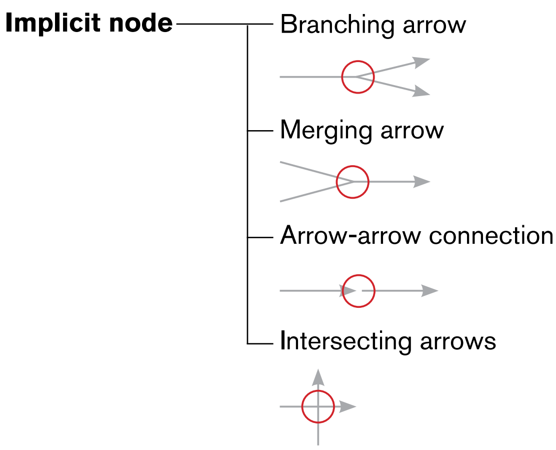

Figure 4.10: Indicator of graphic ineffectiveness – implicit nodes

Imprecise nodes

Graphic objects placed in close spatial proximity to two different graphic objects. This may cause ambiguity about the syntactic role of the imprecise element, whether the represented element is connected or connecting.

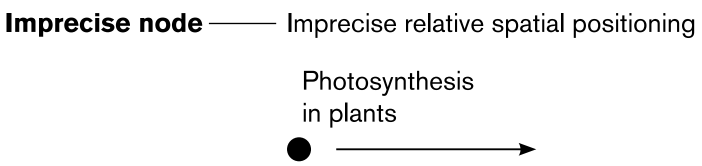

Figure 4.11: Indicator of graphic ineffectiveness – imprecise nodes

Implicit and imprecise nodes are both included as individual coding values in the coding scheme. Where the first two indicators of graphic ineffectiveness relate to the spatial positioning of graphic objects, the following two relate to the number of information types represented within groups of visually similar graphic objects.

Polysemy

Polysemy occurs when a single or a group of visually similar graphic objects represent more than one information type. Unlabelled arrows and pictorial objects are instances of single polysemic nodes. Polysemy may also occur within a diagram, when visually similar nodes or connectors represent different information types. This latter type of polysemy is thereby an ineffective graphic tactic which results from the combination of coding values – *ie,* graphic tactics – within a diagram [figure 4.12].

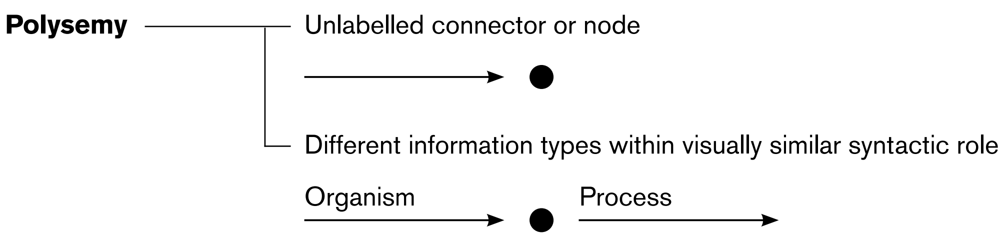

Figure 4.12: Indicator of graphic ineffectiveness – polysemy

When identifying visually similar nodes or connectors, in relation to polysemy, the combination of graphic objects applied in individual nodes is taken into account. This is needed when a node or connector consists of a cluster of graphic objects. For example, a node may include a pictorial object and a text object as a label which is also contained. Thereby three types of graphic objects are applied in one node. Visual similarity here relates to nodes or connectors with similar combinations of graphic objects and other graphic syntax aspects.

Inconsistency

The final indicator of graphic ineffectiveness relates to the categories of information created through individual 'attribute-based relations' (Engelhardt, 2002) [figure 4.8, p. 106]. This indicator is similar to polysemy, but has a narrower analytical focus by analysing different attributes separately, to reveal the consistency with which it is applied. Here it is inconsistent to represent, for example, three different information types with the same colour or typographic attribute (Bertin, 1983) [figure 4.13, next page]. Inconsistency is also identified within the verbal syntax of text objects. This analysis relates to 'cognitive ergonomics' and the principle of 'redundancy gain' (Backs and Walrath, 1995; Selcona *et al*, 1995) or 'positive redundancy' Garland (1968).

Positive redundancy, within information design, relates to recurring patterns in the way information is represented, *eg,* placing page numbers in the same position on every page. In the narrower focus of text objects in network diagrams, positive redundancy here relates to applying the same verbal syntax in each visually associated object, this could be nouns in nodes and verbs in arrow labels. Inconsistent verbal syntax is when, for example, one node includes *eg,* 'photosynthesis in plants' and the next node includes 'animals'. Where the first node represents a spatial relationship between a process and an organisms, the next node includes only an organism, *ie,* no spatial relation indicated. Thereby, the verbal syntax pattern is broken; it is inconsistent. This indicator of graphic ineffectiveness is one of the theoretical contributions of this thesis. It reveals how verbal syntax patterns may affect the information categorisation in network diagrams, and the message about the content proper. This research enquiry also demonstrates how to systematically identify ineffective graphic tactics that are verbal syntax related.

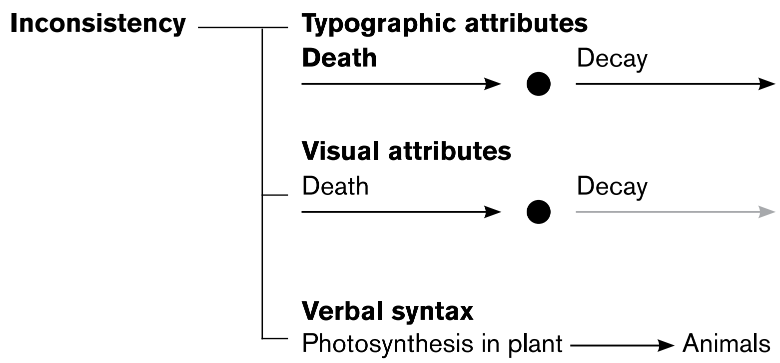

Figure 4.13: Indicator of graphic ineffectiveness – inconsistency

A graphic object may represent two or more indicators of graphic ineffectiveness. For example, an implicit nodal point is also polysemic – similar to an unlabelled arrow – and inconsistent colour coding, *eg,* one colour applied to all arrows, creates polysemy within the arrows if more than one information type is represented. They are included as separate measures in this research enquiry to triangulate the coding values and provide deeper detail on the application of different individual graphic tactics. The third, and final, theoretical component of the coding scheme is the general information types in ecological cycle network diagrams.

4.3.2.3 General information types in ecological cycle network diagrams

At a curriculum level for the 14-18 years age groups in the UK and Denmark (UVM, 2009 and 2007; DFCSA/QCA, 2007), the ecological cycle subjects include three main information types: physical elements – some microscopic, some large masses – processes, and energy/force. Such information may be classified in various ways depending on the scientific context. In this thesis, the definition of information types is informed by the terminology extracted from the collected ecological cycle network diagrams as part of the pilot analysis [section 3.2.3, p. 76]. This results in a semantic classification in which the information types are defined based on verbal descriptions in existing diagrams. This analytical strategy is necessary due to the terminology in existing diagrams which reflects the audience levels, *ie,* 14-18 year age groups, and so is less technical. Existing ecological cycle network diagrams, include a range of terminology, from chemical notation, *eg,* 'CO_2', over 'carbon dioxide', and broader terms such as 'dead organic matter', 'waste', 'fossil fuel', 'soil', and 'sea' – often in the same diagram.

In the semantic definition applied in this research enquiry, physical elements consist of four information types: organisms, matter, material, and pool. **Organisms** are living things, *eg,* microbes, plants, humans, and animals. **Matter** is in this thesis defined as elements described precisely by chemical notation or terminology, *ie,* 'CO_2' and 'carbon dioxide'. **Material** is a – semantic – broader category of matter referring to larger masses of matter, *ie,* 'waste' or 'fossil fuel'. Matter may further be stored, continuously, in a **pool**, *eg,* 'sea'. The **processes** and thus circulation of matter is fuelled by **energy and force**, *eg,* solar energy fuelling photosynthesis. Section 4.4.1.6, [p. 126] includes a detailed outline of the terms identified as representing each information type in this research enquiry. This provides transparency and consolidates any analytical confusion cased by the semantic definition strategy. For now, the six information types are summarised in figure 4.14.

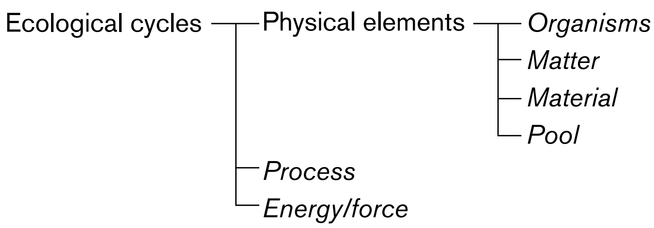

Figure 4.14: Information types in ecological cycles for 14-18 year age groups.

The three theoretical components of the coding scheme – graphic syntax aspects, indicators of graphic ineffectiveness and general information types in ecological cycle network diagrams – are synthesised in the definition of coding values, the smallest units of analysis within the coding variables. These coding values in turn enable identification of the information that is represented in diagrams within the data set, how it is categorised using graphic syntax, and whether ambiguity may potentially result from the information categorisation within and between nodes and connectors.

4.4 Coding variables

At the core of a reliable and replicable visual content analysis is a set of precisely defined coding variables and coding values (Rose, 2007; Bell, 2003). Each coding variable and its values are here defined and demonstrated. The entire coding scheme is then presented in figure 4.51 [p. 154], this provides an overview for transparency and enables discussion of the represented design problem space.

4.4.1 Coding variable 1 – node and connector syntactic roles

The first coding variable is the central element in this coding scheme, given the defining roles of nodes and connectors in network diagrams. The aim with this coding variable is to identify which information is represented in nodes and connectors and, thereby, the information types that are represented as connected or connecting in the data set. Arrows are commonly perceived as dynamic graphic objects actively connecting (Richards, 1984; Bertin, 1983; Engelhardt, 2002; Tufte, 2006; Krull and Sharp, 2006), whereas nodes take on a more passive syntactic role by being connected in their object-to-object relations.

Richards' (1984) offers insight to the relationship between nodes and connectors through an analogy between graphic syntax and the object/predicate space of verbal syntax. In Richards' model [figure 4.15, next page], the 'graphic display' (Richards, 1984: 3/25) is a generic term for a combination of graphic objects applied to depict a content proper, an ecological cycle network diagram in this thesis. The 'content model' (Richards, 1984: 3/25-26) refers to a mental construct; the reader's spatial interpretation of 'what is shown' in the graphic display. Richards applies grammatical categories to interpret the diagrammatic space (Richards, 1984: 3/26)

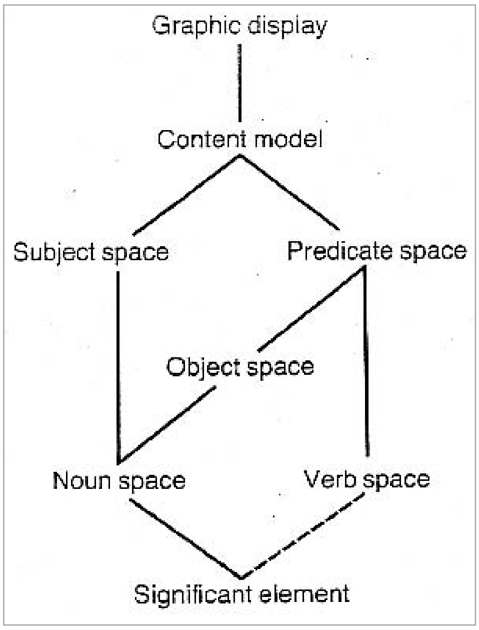

Figure 4.15: From Richards (1984: 3/27)

In this way, the 'content model' consists of subject spaces or predicate spaces. In grammar, a predicate space is the space in the sentence that contains the verb, or which says something about the subject. Thus the predicate space may be a verb-space or an object-space. As in grammar, the relation between subject space and object space is based on the verb space, however, in diagrams a verb space may be represented by empty space. A diagram's noun-space is analogous to a verbal subject or object (Richards, 1984:3/26).

In network diagrams nodes generally serve as noun spaces and connectors as verb spaces, creating two categories of information: connected and connecting elements. A clear visual distinction between nodes and connectors in diagrams is therefore important. Without this, the graphic syntax may create an ambiguous explanation of the essential relationships between the content proper elements. However, in the pilot content analysis of this research enquiry, several instances of composition proved challenging to identify as nodes or connectors. This was due firstly, to the flexible physical characteristics of nodes, compared to the more clearly definable arrow shape. Secondly, the challenge was that some arrows serve in simultaneous connector and node syntactic roles, forming implicit nodes [section 4.4.1, p. 115].

Graphic objects serving as connectors are relative simple to identify, based on their arrow shape [figure 4.16]. In this research enquiry, an arrow head is the minimum requirement for an object to qualify as such.

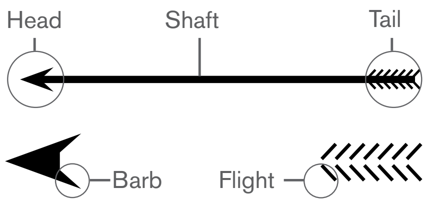

Figure 4.16: Visual definition of arrow graphic object, based on Horn (1998) to which is added flights.

In contrast to arrow shapes, the physical characteristics of nodes receive less attention in reviewed literature, for example, Engelhardt (2002) and Richards (1984) both focus on defining the syntactic role. Bertin (1983: 276) offers more detail defining a node as a point; a definition reminiscent of Mathematical Graph Theory (Nelson, 2008). This definition was applied in the pilot analysis in which a node was defined as a graphic object positioned between an arrow tail and an arrow head. The definition was insufficient, however, as the pilot analysis unravelled implicit nodal points, created by branching, merging and intersecting arrows. This scrutiny of the data set also revealed empty nodal points – created by two connected arrows – and arrow shafts interrupted by text objects, creating ambiguity about the syntactic role. Figure 4.17 demonstrates arrow shafts interrupted by text objects.

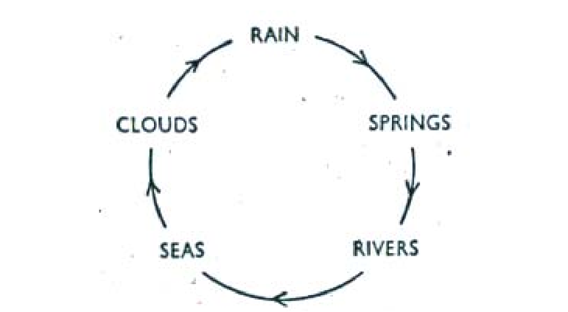

Figure 4.17: Diagram no 029

Graphic syntax aspect highlighted
Identification of nodal point:
Text graphic objects interrupting arrow shafts.

The water cycle
From: Daniel (1954: 102)

The text objects in figure 4.17 do not qualify as nodes if defined as a graphic object between an arrow tail and head. Figure 4.17 would then include arrow labels only. However, the included information types are pools, *eg,* 'sea' and material, *eg,* 'clouds'. In the content proper context, these physical elements are connected by the circulation of water[3]. The verbal nouns also suggest that the graphic objects inhabit noun spaces rather than verb spaces. As such they qualify as nodes according to Richards' (1984) theory. This example elucidates the intricate and at times complicated relationship between 'what is shown' by graphic syntax and the resulting message about the content proper. In relation to this research enquiry, it results in elaborating the definition of a node and defining three overall groups of coding values as implicit, imprecise, and explicit nodes [figure 4.18]. Only explicit connectors are identified, given the clearly distinct arrow shapes.

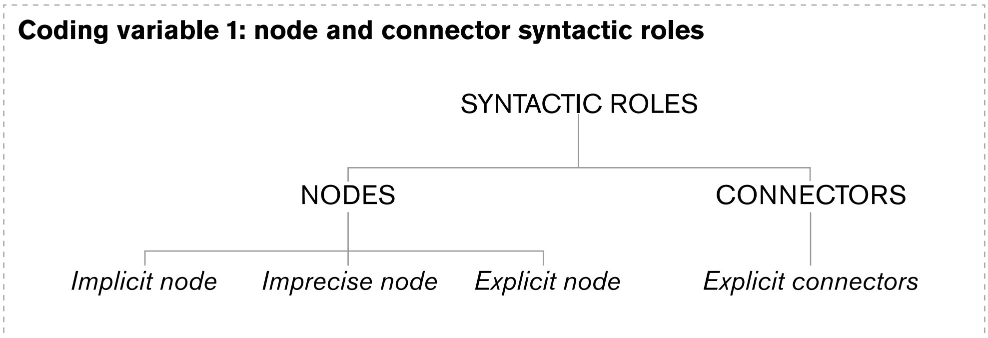

Figure 4.18: Overall groups of coding values for nodes and connectors.

Explicit nodes are in this thesis identified as a single or a combination of graphic objects connected to one or more arrows. A node may be positioned by an arrow head, tail, or interrupting the arrow shaft. A graphic object representing an imprecise node – *eg*, interrupting the arrow shaft – may be distinguished as a node if it includes a subject-space related information type – matter, material, organisms, and pools – and through its distinct visual or typographical attributes. The coding value for imprecise nodes is here a special case. This coding value is used to quantify the number of diagrams which include instances of nodes that are not positioned between arrow heads and tails. This coding value is thereby an addition to the explicit node coding values, providing deeper detail on the precision within the data set.

3 Although rivers and rain often are included as connecting elements in water cycle diagrams. This indicates additional potential ambiguity in this diagram.

The need for considering the visual and typographic attributes when identifying explicit nodes is demonstrated by figure 4.19. Here the nodes are identified by their upper case typographic attributes, whereas lower case italic characterises the arrow labels. The text object 'ANIMALS' [a] is therefore identified as a node, although interrupting the arrow shaft.

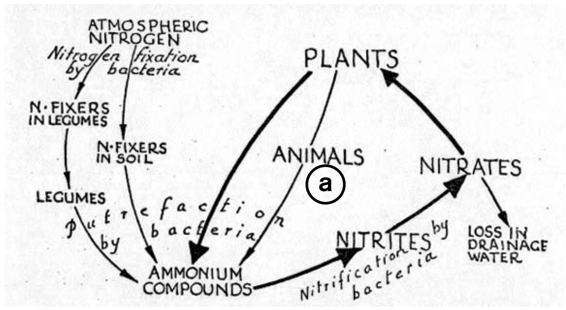

Figure 4.19/ Diagram no 032

Graphic syntax aspect highlighted
Identification of nodal point:
'ANIMALS' identified as a node based on content proper information type and typographic attribute.

The nitrogen cycle
From: Palmer (1954: 120)

The coding values for implicit and imprecise nodes represent the two related indicators of graphic ineffectiveness [section 4.3.2.2, p. 110]. This results in six coding values, each of which are presented in the following sub-sections [sections 4.4.1.1-6]. Then follows the coding values for explicit nodes and connectors [sections 4.4.1.6-7, p. 124].

4.4.1.1 Implicit node – branching arrows

Several diagrams in the data set include arrows with branching or merging arrow shafts. Such an arrow could be identified as a single connector – the branching points simply part of the arrow shape. An alternative view, however, derives from botany where a node is 'the part of a plant stem from which one or more leaves arise' (Daintith and Martin, 2005: 354). Following this, the point of branching can also be interpreted as a node. In the content proper context, the physical cycle then includes a point – in time or space – at which something happens, causing the connecting elements to diverge. If read as a node, the point of branching is itself connected and inhabits a noun-space.

In figure 4.20 the 'organic compounds in dead organisms' [a] is connected by an arrow [b], which branches into two shafts, representing a total of three processes: 'respiration' [c] and 'decay and decomposition' [d]. These arrows in turn point to the node 'CO_2 in the air and dissolved in water, particularly oceans' [e]. This ineffective graphic tactic creates two content proper ambiguities: does the initial singular arrow shaft represent all three processes or just the one? And, which event – in the carbon cycle – takes place at the point of branching/divergence, causing the separation of processes.

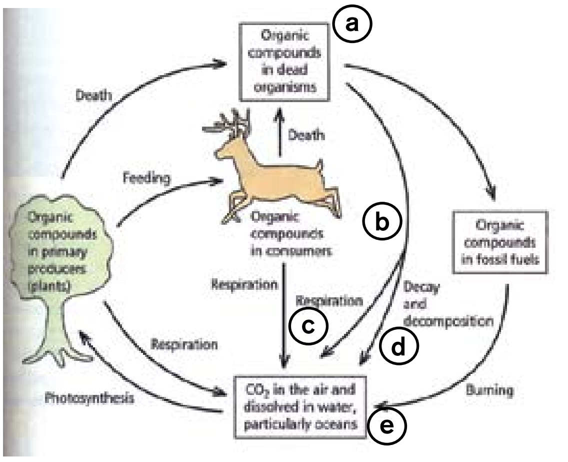

Figure 4.20: Diagram no 133

Graphic syntax aspect highlighted
Implicit nodal point:
Branching arrow

The carbon cycle
From: Fullick and Fullick (2000b: 519)

4.4.1.2 Implicit node – merging arrows

Merging arrows represent the same ambiguity as branching arrows, the content proper elements here converging. In figure 4.21 three nodes: 'nitrogen-fixing bacteria in the soil' [a], 'nitrogen-fixing bacteria in root nodules…'[b], and 'lightning' [c] are connected to 'nitrates in the soil' [d] by three arrow shafts [e] which merge in the main shaft and point to the node. Here a similar question arises about what takes place in the content proper at the points where one arrow meets another.

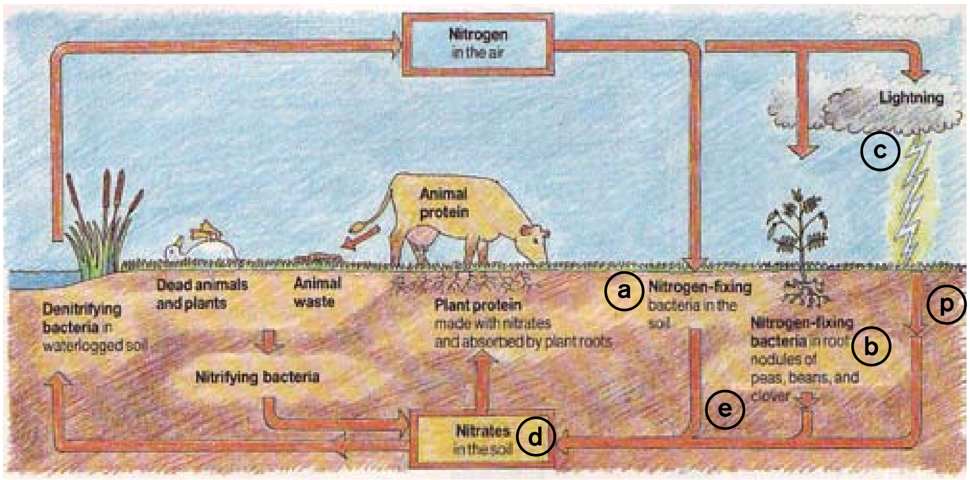

Figure 4.21: Diagram no 200

Graphic syntax aspect highlighted
Implicit nodal point:
Merging arrow

The nitrogen cycle
From: Beckett and Gallagher (1993: 167)

4.4.1.3 Implicit node – arrow connected to arrow

Staying with figure 4.21, a smaller arrow [p] exits the 'lightning' node [c], points to the tail of the triple-shafted arrow [e] which connects to the 'nitrates in the soil' node [d]. As such the smaller arrow [p] is connected to a node and to another arrow. Bertin (1983: 347) suggests that repeated arrows increase the perception of movement and direction. This could explain the graphic tactic in figure 4.21, but applies less easily to figure 4.22 [next page].

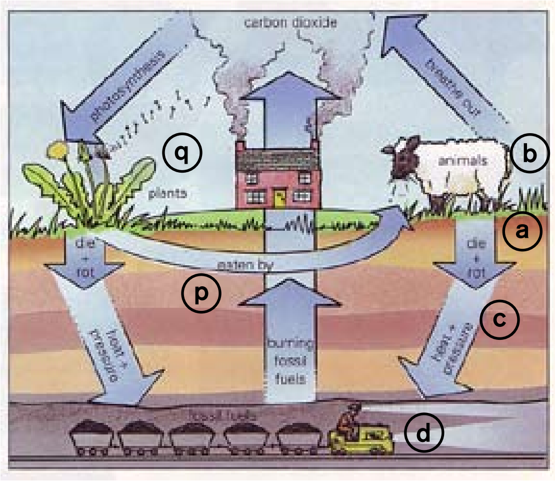

Figure 4.22: Diagram no 183

Graphic syntax aspect highlighted
Implicit nodal point:
Arrow connected to arrow
Arrow superimpositioned on arrow

The carbon cycle
From: Bethell *et al* (1996: 85)

Here an arrow labelled 'die+ rot' [a] connects the sheep [b] and another arrow 'heat + pressure' [c]. The latter arrow connects 'die + rot' and the pictorial 'fossil fuel' node [d]. These two arrows could be interpreted as serving simultaneous node and connector roles. In relation to the content proper message this ineffective graphic tactic leaves the reader to wonder what happens at the point of connection; what transforms 'die and rot' into 'heat and pressure' – *ie,* two processes into energy and force? Where an empty verb-space is acceptable – potentially significant – in accordance with Richards' model [section 4.4.1, p. 115], an 'empty' noun space is puzzling. This is even more so in figure 4.22, given that three instances of empty nodal points occur.

4.4.1.4 **Implicit node – intersecting arrows**

Figure 4.22 also includes an arrow [p] – connecting the plant [q] and the sheep [b] – which is superimposed on top of another arrow. In this particular case the two connectors are visually clearly distinct. Several examples within the data set are more ambiguous. In figure 4.23 arrows overlap, creating intersections. Overlapping is distinct from superimposition by the arrows occupying the same layer within the diagrams. Superimposition includes one object on top of another (Engelhardt, 2002: 21). In Mathematical Graph Theory – a 'graph' refers to lines connected by sets of points and node refers to 'a singular point at which a curve intersects itself such that there are two different tangents at the point' (Nelson, 2008: 68). Based on this theory, in figure 4.23, the junction created by the overlapping arrows represents a node created by the two intersecting connectors. In the content proper context, it is unclear what causes the intersection of connecting elements. Examples of older diagrams, *eg,* figure 4.24 solve this problem by adding small arches to the overlapping arrow. This graphic tactic is only seen in three examples in the data set, all published prior to 1940.

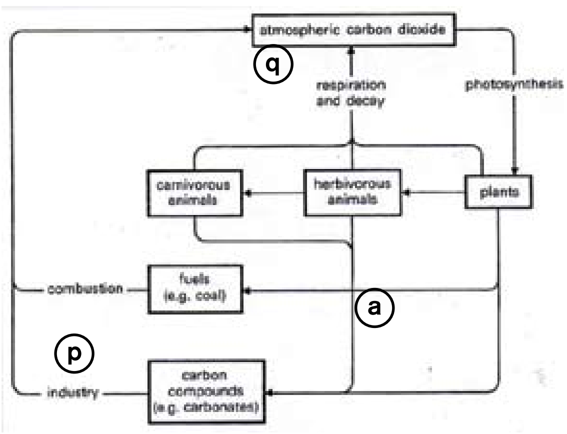

Figure 4.23: Diagram no 086

Graphic syntax aspect highlighted
Implicit nodal point:
Intersecting arrows

The carbon cycle
From: Davies *et al* (1973: 270)

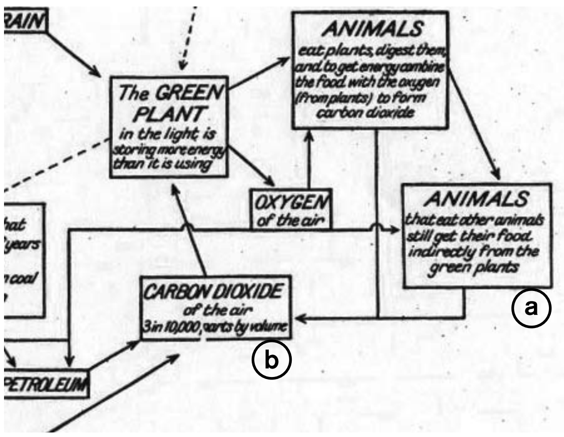

Figure 4.24 / *Detail* from Diagram no 123

Graphic syntax aspect highlighted
Arching arrow shafts

Detail from Bryant (1937: 34)

4.4.1.5 Imprecise node – relative spatial positioning

This coding value is defined to enable transparency about how many diagrams include an instance of an imprecise node. An imprecise node is here defined as an instance of a graphic tactic which includes imprecise spatial relation of a graphic object relative to other graphic objects, *eg,* an arrow label which may be read as a node, *ie,* those graphic tactics that require consideration of either the information type included, the visual attribute, or the typographic attributes to determine the syntactic role. The 'ANIMALS' node [a] in figure 4.19 [p. 119] is an example of an imprecise node.

The implicit and imprecise coding values directly represent the related indicators of graphic ineffectiveness [section 4.3.2.2, p. 110]. Each of the five coding values thereby represent a general ineffective graphic tactic [figure 4.25].

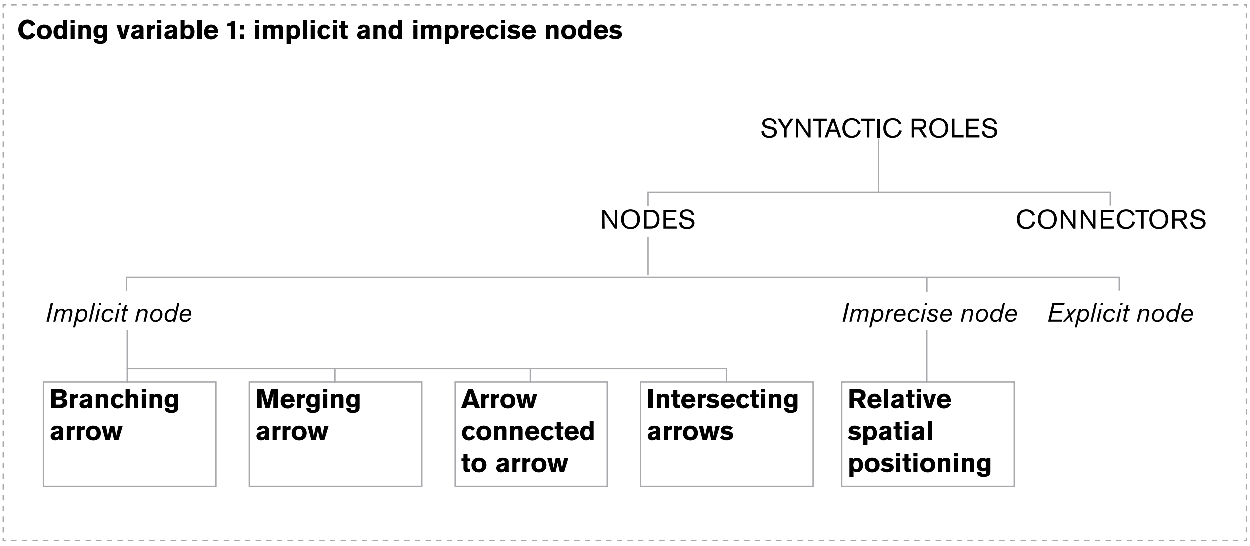

Figure 4.25: Overview of coding values for implicit and imprecise nodes.

4.4.1.6 Explicit nodes and connectors – single information type

The coding values for explicit nodes enable identification of the information represented in nodes and connectors, and, in turn, the information types that are represented as connected or connecting in the data set. These coding values then form the core of the coding scheme. Explicit here refers to the intention of the graphic objects. Where implicit nodes may be unintentionally applied in this syntactic role, an explicit node or connector is a graphic object which is clearly intended as such. However, an explicit node or connector may be unlabelled – for example an unlabelled arrow – in which case the syntactic role is explicit, but the information type is implicit.

Three general graphic tactics for representing information in explicit nodes were identified through the pilot content analysis. A single node or connector may be unlabelled – *ie,* polysemic – it may include one information type, *eg,* 'plants' or it may include multiple information types, *eg,* 'photosynthesis in plants' which represents a process in an organism. These overall graphic tactics within explicit syntactic roles are summarised in figure 4.26 [next page]. The coding values for single information types and multiple information types are expanded below.

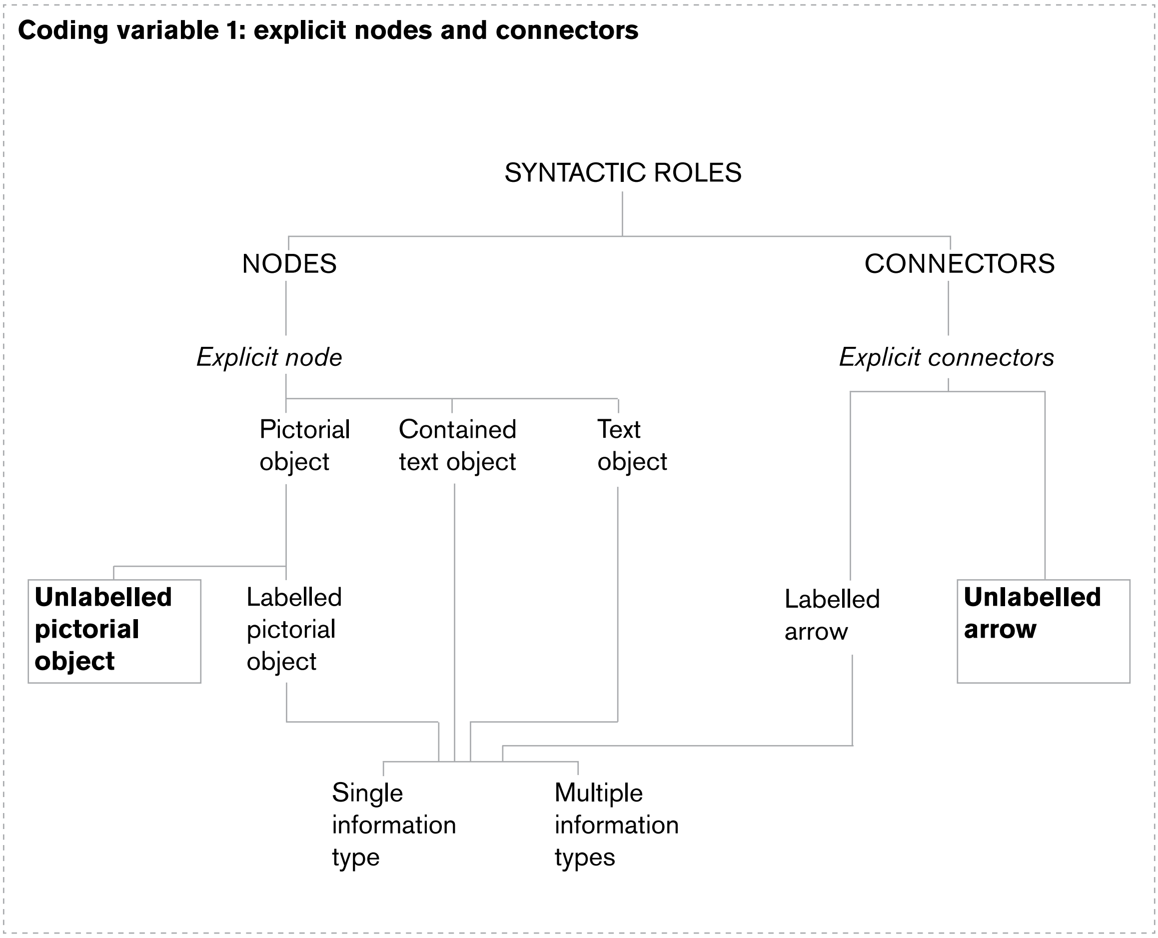

Figure 4.26: Overall groups of coding values for explicit nodes and connectors. Unlabelled pictorial object and an unlabelled arrow represent single coding values and general ineffective graphic tactics. Single information types and multiple information types are expanded below.

Individual coding values are defined for each of the six information types, unlabelled pictorial objects, and unlabelled arrows. The information type represented by a singular text object is here identified based on the semantic definitions developed for this research enquiry. Table 4.1 summarises these coding values with a broad outline of the semantic definition of information types. A detailed definition is included as appendix 5.

Coding values: explicit nodes and connectors, single information types or unlabelled.	**Identification**
Organism	Any living organism: *eg,* animal, human, plant, bacteria, microbe, decomposer.
Matter	Matter described by scientific terminology: *eg,* atmospheric nitrogen, H_2O, plant protein, protoplasm of animals, ammonium salts.
Material	Larger human made or naturally occurring masses of matter, and more inclusive terminology, *eg,* tissue, water, salts, dead organic material.
Process	Processes described with nouns or verbs: *eg,* photosynthesis, eat, eaten, decomposed, decomposes.
Pool	Large masses of continuous stored matter: *eg,* air, sea, lake, river, soil.
Energy/force	Explicit mention of energy or force: *eg,* chemical energy.
Unlabelled pictorial object	Pictorial object with no label.
Unlabelled arrow	Arrow object with no label.

Table 4.1: overview of coding values: explicit nodes and connectors – single information types

The elements defined as material in this research enquiry unravels the broad nature of content included in existing visual output. The group of elements here defined as material could be further distinct *eg,* by organic/inorganic material, or man-made/natural material. However, the relatively broad definition is sufficient for identifying polysemy through the visual content analysis in this research enquiry. Sub-categories within the material information type are taken into account when reviewing the consistency of visual and typographic attributes [section 4.4.4, p. 139 and 4.4.5, p. 147].

4.4.1.7 Explicit nodes and connectors – multiple information types

The final two coding values for the first coding variable are defined to identify nodes and connectors that include multiple information types. Two general graphic tactics exist within these types of nodes and connectors. A group of nodes or connectors which include multiple information types may be monosemic or polysemic. This relates to whether a recurring verbal pattern is created in the way the coding values are combined within or between nodes or connectors. A verbal pattern may be created in a group of nodes or connectors by including an invariable information type combined with different variable information types.

A **monosemic** pattern of 'multiple information types' is when the invariable information type is consistent within visually similar nodes or connectors. In figure 4.27 three nodes are contained in rectangular shapes: 'organic compounds in dead organisms' [a], 'organic compounds in fossil fuels' [b], and 'CO_2 in the air and dissolved in water, particularly oceans' [c]. Two nodes are represented by a labelled pictorial object 'organic compounds in consumers' [e] and 'organic compounds in primary producers (plants)' [d]. Matter is here the invariable information type, whereas material, pool, and organism are variable information types. These five nodes are identified as 'multiple information types – monosemic', because categories are created in which contained text objects represent '*matter* in *material* or *pool*', and text object with pictorial objects represent '*matter* in *organism*'. This means that none of the variable information types appear in two visually distinct categories. Visual similarity is in this coding value identified based on the three types of basic graphic objects – text, shapes, and pictorial objects – and visual or typographic attributes.

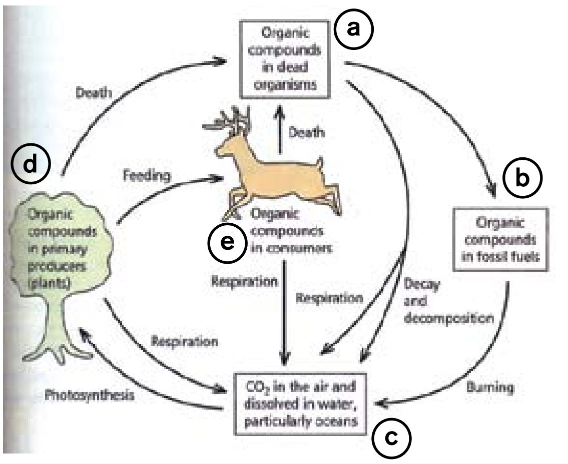

Figure 4.27: Diagram no 133

Graphic syntax aspect highlighted
Node and connector syntactic roles:
Explicit nodes, multiple information types monosemic

The carbon cycle
From: Fullick and Fullick (2000b: 519)

Polysemy happens in two ways within the multiple information type coding value:

- If no invariable information type is included, *eg*, one node is '*matter* in *pool*', another is '*process* in *organism*'. This fails to establish a logical pattern.
- If an invariable information type is consistent, but a variable information type is included in two nodes which are visually distinct.

An interesting twist has happened in figure 4.28, deriving from the same author as figure 4.29. The two diagrams include identical verbal content, but the composition, visual attributes, and pictorial objects are changed.

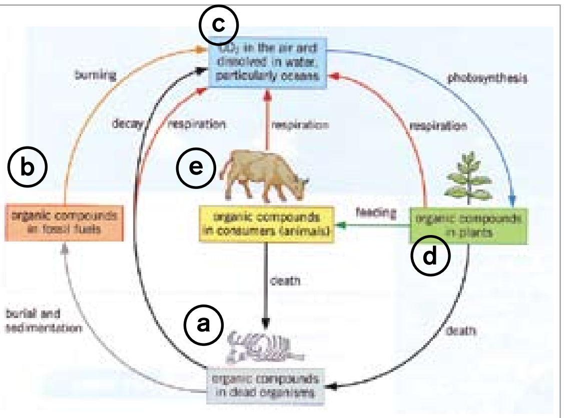

Figure 4.28 / Diagram no 138

Graphic syntax aspect highlighted
Node and connector syntactic roles:
Explicit nodes, multiple information types monosemic

The carbon cycle
From: Fullick and Fullick (2001b: 76)

In figure 4.28 matter is still the invariable information type, whereas the invariable information types are material, pool, and organism. However, figure 4.28 is identified as 'multiple information types – polysemic'. The ineffective issue is here the inclusion of a pictorial object for node [a], whilst node [b] is left as contained text only. Although the five nodes are disassociated by colour coding, categories are created based on combining different types of graphic objects. Here the contained nodes represent 'matter in material' [b] or 'matter in pool' [c], however a contained node with a pictorial object may also represent 'matter in material' [a] – or organism [e and d]. This means that a variable information type appears in both visual categories of nodes.

These two coding values for multiple information types are summarised in table 4.2.

Coding values: explicit nodes and connectors, multiple information types	**Identification**
Multiple information types – monosemic	Analysis within nodes or arrows: Consistent invariable and variable information types in different groups of visually associated nodes or connectors. [figure 4.27]
Multiple information types – polysemic	Analysis within nodes or arrows: No invariable information type is included; failing to establish a logical verbal pattern. OR Consistent invariable information type but one or more variable information types are included in visually disassociated nodes or connectors. [figure 4.28]

Table 4.2: Coding values for nodes and connectors with multiple information types.

Coding variable 1 is summarised visually in figure 4.29 [A3 fold out], with coding values and indicators of graphic ineffectiveness integrated. Four of the coding values for explicit nodes represent general ineffective graphic tactics. The coding values which do not represent a general ineffective graphic tactic may be described as 'neutral' when analysed as single units. However, the combination of any of these coding values may result in polysemy within the nodes or connectors respectively. This ineffective graphic tactic, which arises from a combination of coding values, relates to the polysemy indicator of graphic ineffectiveness. These instances are identified in a procedure similar to 'multiple information types – polysemic' and are discussed in chapter 5.

A3 fold out: FIGURE 4.29
CODING VARIABLE 1

4.4.2 Coding variable 2 – pictorial objects

Coding variable 2 is defined to reveal further detail about graphic tactics for using pictorial objects. Pictorial objects occur only in nodes within the data set. The coding values here relate to the information included in pictorial object labels. In Engelhardt's framework, 'labelling' is a syntactic role of an object anchored to another object (2002: 34). The label specifies information about the depicted content proper element. The information types included in pictorial labels play an important part in the coding scheme for this research enquiry. Firstly, pictorial objects labels are used for identifying explicit nodes in the ecological cycle network diagrams which include 'integral metric spaces', *ie,* diagram groups 5 and 6 [section 4.2.1.1, p. 102]. Secondly, the relationship between the pictorial objects and the information included in their labels may create additional categories of information within a diagram; thirdly, polysemy may arise from the combination of coding values within pictorial objects in a diagram. In diagram groups 3 and 4 [section 4.2.1.1, p. 102] pictorial objects occur exclusively in nodal positions. Identifying nodes in integral metric spaces, diagram groups 5 and 6, is more challenging, because the nodes are part of an illustration. Here the labels may be used for identifying nodes. Figure 4.30, for example, comprises five nodes [a-e] and seven unlabelled connectors.

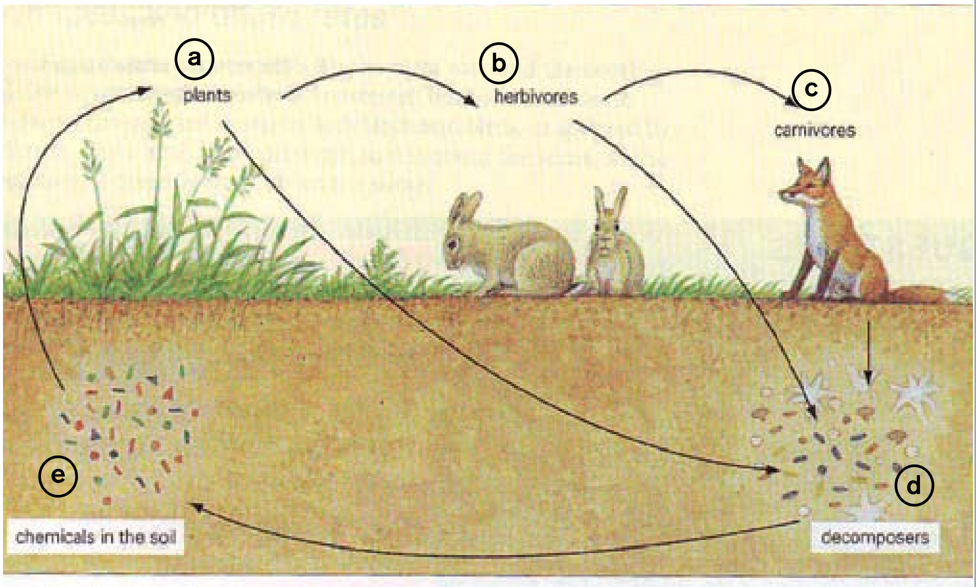

Figure 4.30: Diagram no 186

Graphic syntax aspect highlighted
Identification of nodes in an integral metric space based on explicit labelling.

The carbon cycle
From: Stuart and Webster (1996b: 28)

The information types included in pictorial object labels are identified through coding variable 1[4]. The focus of coding variable 2 is the type of relationship between a pictorial object and what is included in its label; and whether all pictorial objects in a diagram include the same type of relationship. Engelhardt (2002: 99) defines three types of relationships between 'what is shown' – here the pictorial object –and 'what is meant' – here the related content proper element. These are 'types of correspondence' (2002: 99)[5]:

- Literal – the graphic object shown is similar to the physical element that is meant.
- Metaphoric – 'what is shown' and 'what is meant' share a function or structural analogy.
- Arbitrary-conventional – 'what is shown' and 'what is meant' is related by convention only.

Engelhardt (2002: 102) makes a further distinction concerning these relationships. When a graphic object or graphic relation corresponds literally to what is meant, then the graphic object or relation is an 'intended referent'; the object means what it shows. In figure 4.31 [next page] the pictorial object of daffodils and snowdrops [a] may be interpreted literally as daffodils and snow drops. In this case the pictorial object is a intended referent. The same object can also be interpreted as a metaphoric or metonymic correspondence. The 'intended referent' then becomes an 'intermediary referent' (2002: 102). The node could now mean 'producer', 'all plants', or 'food' *etc*.

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4 The nodes in figure 4.30 are here identified as organism – 'plants' [a]; 'herbivores' [b], 'carnivores' [c], 'decomposers' [d] – and 'multiple information types monosemic' – 'chemicals in the soil' [e]. The connectors are all unlabelled.

5 For elementary graphic objects, Engelhardt (2002: 99) adds 'rebus-based' and 'metonymic correspondences'; based on similarity in the sounds of (part of) the spoken word for 'what is shown' and 'what is meant', or the graphic object shown being 'part of' or 'a possible result of' 'what is meant'.

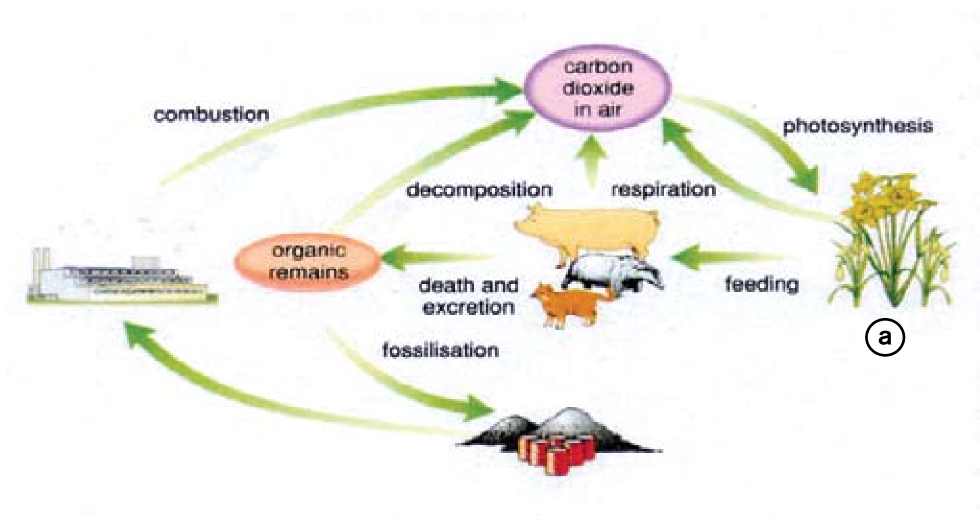


Figure 4.31: Diagram no 136
Graphic syntax aspect highlighted Pictorial object interpretation: Daffodils: Literal correspondence/Intended referent Producers: Metaphoric/Intermediary referent
The carbon cycle From: Dawson and Honeysett (2001: 77)

Figure 4.31 demonstrates the polysemic nature of a single, unlabelled pictorial object. Bertin mentions this polysemic nature as the reason for omitting pictorial objects in the scope of his theory (Bertin, 1983: 2). He does however, include shapes, *eg,* map symbols which could appear polysemic, but are rendered monosemic by explicitly stating their meaning in a legend. Within pictorial objects and arrows in network diagrams, monosemy may be ensured by adding a label. The types of correspondence here represent different graphic tactics, determined by the label content. In figure 4.30 [p. 131] the pictorial rabbits [b] are labelled with 'herbivores', representing and intermediate referent. Figure 4.32 [next page] applies intended referents by labelling the fox [a] and rabbit [b] as 'fox' and 'rabbit',

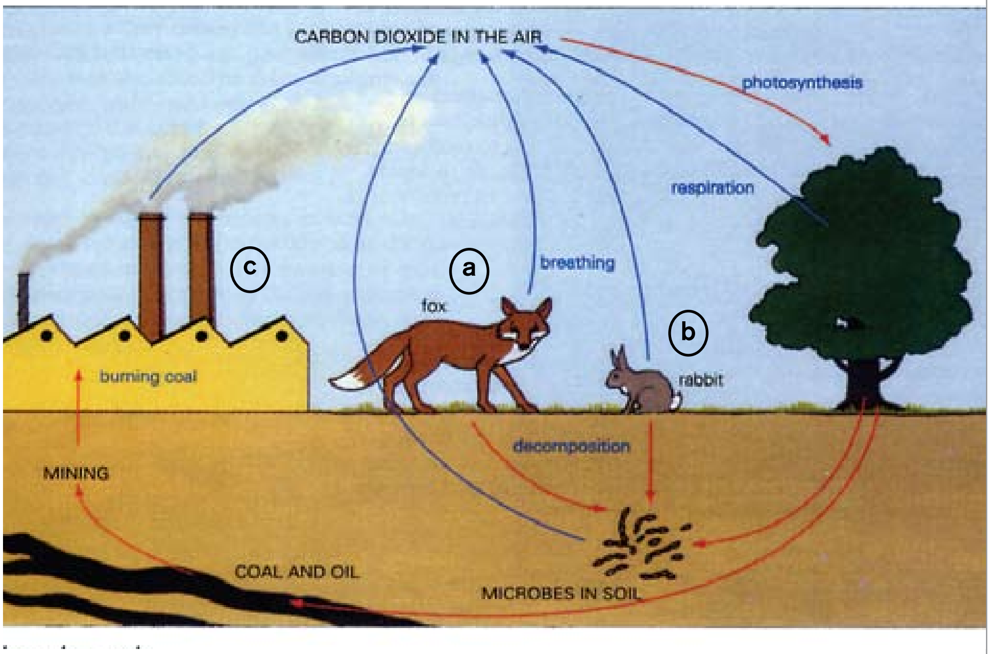


Figure 4.32: Diagram no 211

Graphic syntax aspect highlighted
Pictorial object interpretation:
Pictorial object labelled 'fox': intended referent
Pictorial object labelled 'burning coal': intermediate referent.

The carbon cycle
From: Stuart and Webster (1999a: 33)

These two graphic tactics correlate with Schriver's (1997: 412-413) 'redundant' and 'complementary' text and image relationships respectively:

- [Purposely] *Redundant* – visuals explain the same information as the text.
- *Complementary* – visuals explain different information to the text.
- *Supplementary* – visuals explain different information from the text, but one mode dominates as essential information, whereas the other serves to reinforce the message.
- *Juxtapositional* – images explain different content to the text, combined the two modes create a visual synergy through a clash between the concepts in each mode.
- *Stage-setting*, is expanded by Gillieson (2008: 184-185) based on Barthes' (1967) '*relay-relationship*'. Often seen in comic strips, this entails one mode applied to introduce or frame information in the other.

Diagram captions may in this context be described as stage-setting. Two coding values are defined for this coding variable to identify the text image relationships within pictorial objects and their labels.

4.4.2.1 Text image relationships between pictorial object labels

A general ineffective graphic tactic for labelled pictorial objects is when the pictorial objects in the same syntactic role include different text and image relationships. In figure 4.32 [previous page] the pictorial labelling tactics are inconsistent because two nodes [a and b] involve intended referents, whilst [c] is an intermediate referent. This breaks the positive redundancy. The coding variable for pictorial objects includes four coding values. The first two are used to identify the text image relationship of individual pictorial objects and their labels. The last two are used for analysing across the diagram and identify whether the combination of text image relationship is consistent or inconsistent [table 4.3].

Pictorial object labels: text image relationships	**Identification**
Pictorial object labelled as intended referent	Literal correspondence between pictorial object and information in label: *eg,* 'fox' and pictorial object of a fox.
Pictorial object labelled as intermediate referent	Metaphoric or arbitrary conventional correspondence between pictorial object and information in label: *eg,* 'consumer' and pictorial object of a fox.
Text image relationship consistent	Pictorial objects in nodes include only intended or intermediate referents: *eg,* 'consumer' and fox pictorial object, 'producer' and plant pictorial object.
Text image relationship inconsistent	Pictorial objects in nodes include both intended and intermediate referents: *eg,* 'fox' and fox pictorial object, 'producer' and plant pictorial object.

Table 4.3: Pictorial object labels: text image relationships. Definitions synthesised from Engelhardt (2002) and Schriver (1997)

Figure 4.33 is an overview of the coding values in relation to the indicators of graphic ineffectiveness. Inconsistent pictorial object labelling also relates to polysemy within the nodes. Polysemy within pictorial objects is identified by analysing the combinations of coding values [section 5.3.3.1, p. 181].

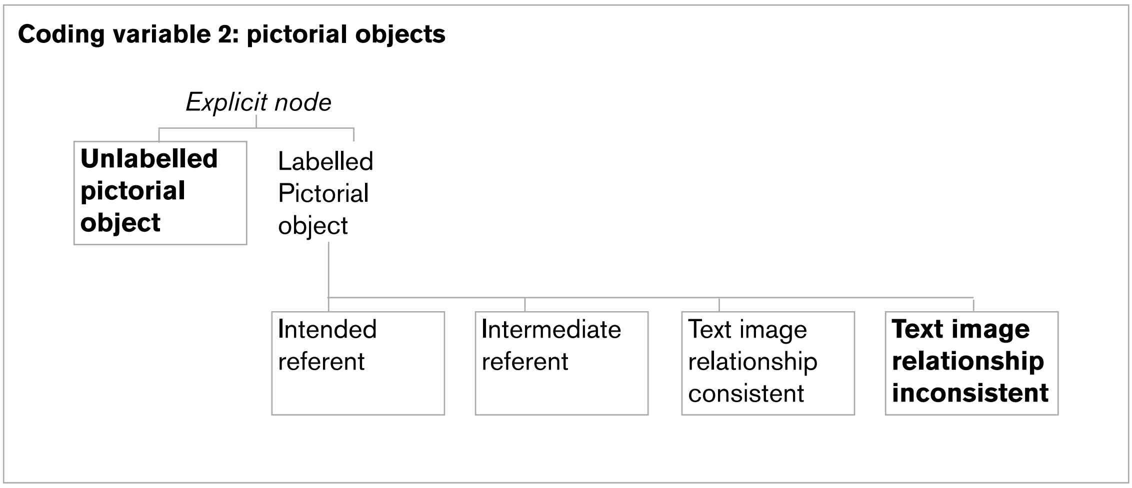


Figure 4.33: Coding values for pictorial object labels. Bold type indicates a value as a general ineffective graphic tactic.

Coding variable 2 focuses on labels anchored in pictorial objects. Labels may also be anchored in arrows. Here the arrow label influences the type of arrow depicted.

4.4.3 Coding variable 3 – arrow types

Coding variable 1 – node and connector syntactic roles – is used to identify the information type included in connector roles within the data set. Coding variable 3 provides deeper detail on the graphic tactics for including information in arrow labels. This happens by revealing how the information included in an arrow label affects the type of arrow and results in additional categories of information. Engelhardt (2002: 42) defines two arrow types:

- Connectors – arrow leading 'from a source object to a target object'.
- Movement arrows– 'physical movement through space of an object'.

Engelhardt expands connector arrows with two types (2002: 102-103): physical links and conceptual links. The former type occurs, *eg*, in wiring diagrams, the latter frequently in ecological cycle network diagrams. For example, in figure 4.34, there are four conceptual links: 'Decay' [a], 'Die' [b and c] and 'Eaten' [d]. These are processes that conceptually connect the elements represented in nodes.

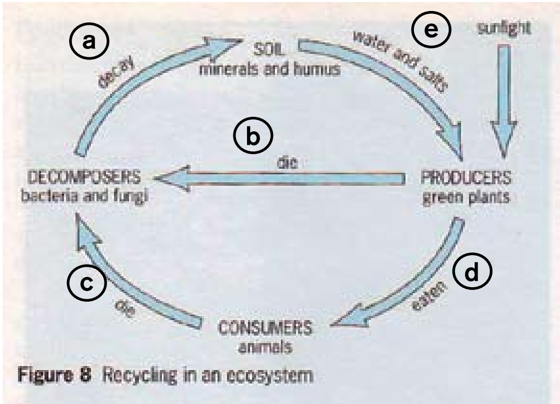


Figure 4.34: Diagram no 053

Graphic syntax aspect highlighted
Arrow type coding value:
Conceptual links [a-d]
Movement between source and target node [e]

MacKean (1995: 236)

Meanwhile, 'water and salts' [e] are substances that move from the soil through a plant's roots. This connector arrow type may be read as a physical link, *ie,* the arrow representing the plant's roots. However, the arrow may also represent the movement through space of salt and water – between a source and a target object. With this finding, Engelhardt's movement arrow is in this thesis distinguished between movement of a source object, and movement of a third entity, *eg,* a carbon atom, between a source and a target object. This refinement of the existing definition is summarised in figure 4.35

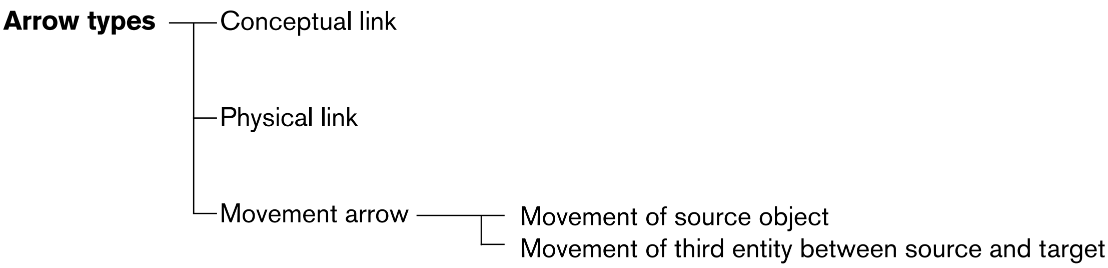


Figure 4.35: Arrow types based on Engelhardt (2002: 42), expanded with two movement types.

In Engelhardt's definition, a movement arrow does not serve the syntactic role of connector (2002: 42). However, in the coding scheme developed for this research enquiry, movement arrows are included as syntactic connectors. This is because the elements in ecological cycles are fundamentally connected by the spatial movement of matter. In this content proper context, movement arrows represent the concept of chemical transfer of matter; conceptual links represent the concepts of chemical transformation. Thereby the arrow types represent two different types of relationships between the connecting elements in ecological cycles, creating two additional categories of information within the ecological cycle network diagrams. The inclusion of movement arrows as connectors also enables analysis of all arrows using coding variable 1 – node and connector syntactic roles. Alignment with Engelhardt's definition would have excluded movement arrows from that coding variable.

4.4.3.1 Explicit arrow types

The type of arrow represented is in this coding scheme identified through the information type included in the arrow label, based on the coding values for single information types [section 4.4.1.6, p. 124]. A label containing a process, *eg,* 'photosynthesis' or 'decomposed', is here identified as a conceptual link; a label containing matter or material, is identified as a movement arrow. The pilot analysis revealed that physical links mainly consist of plant roots or rivers, *ie,* organisms and pools. The arrow type resulting from arrow labels with multiple information types, *eg,* 'nutrients absorbed through plant roots', are not interpreted. These arrow labels are analysed solely through the connector values in coding variable 1 [section 4.4.1.7, p. 126]. However, these values are included when looking within the arrow types in a diagram to identify whether polysemy occurs [section 5.4.2.1, p. 186]. Table 4.4 summarises the coding values for arrow types, figure 4.36 the values in relation to coding variable 1.

Coding values: arrow type	**Identification**
Conceptual link	Information type included in label: process
Physical link	Information type included in label is physically linked to another element, *eg,* plant roots, rivers *etc.*
Movement of source	Information type included in label is the same as in the node source-object, *eg,* a node which includes ‘nitrates’ and an arrow label which includes ‘nitrates’.
Movement between	Information type included in label is not a process-value, or the same as in source node.

Table 4.4: Arrow type coding values

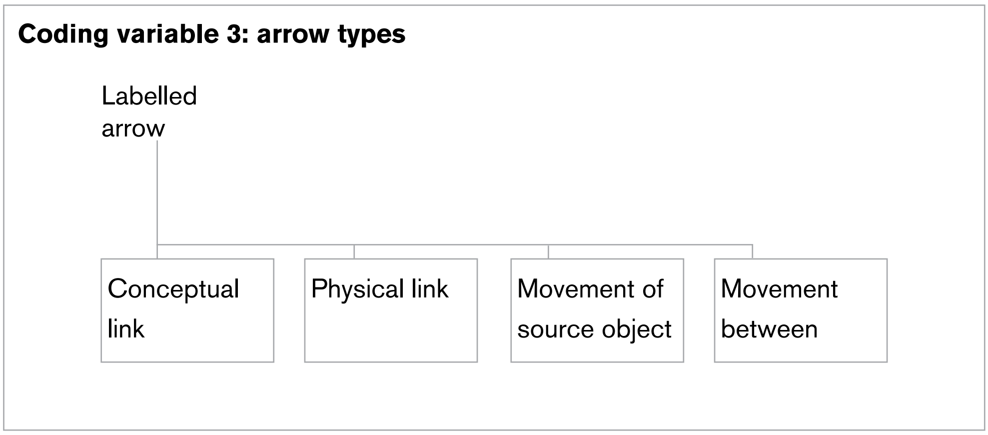


Figure 4.36: Coding values for arrow labels in relation to coding variable 1.

4.4.4 Coding variable 4 – visual attributes

Coding variable 1 – node and connector syntactic roles – demonstrates how information included in a diagram is grouped in two fundamental categories of information: connected and connecting. Visual attributes are here taken into account when identifying polysemic nodes and connectors. Coding variable 4 is used to identify simultaneous sub-categories – within and between the nodes and connectors – created by different visual attributes. Visual attributes may be described as the basic palette available for an information designer. This pallet was formalised by Bertin (1967/1983) as summarised in figure 4.37.

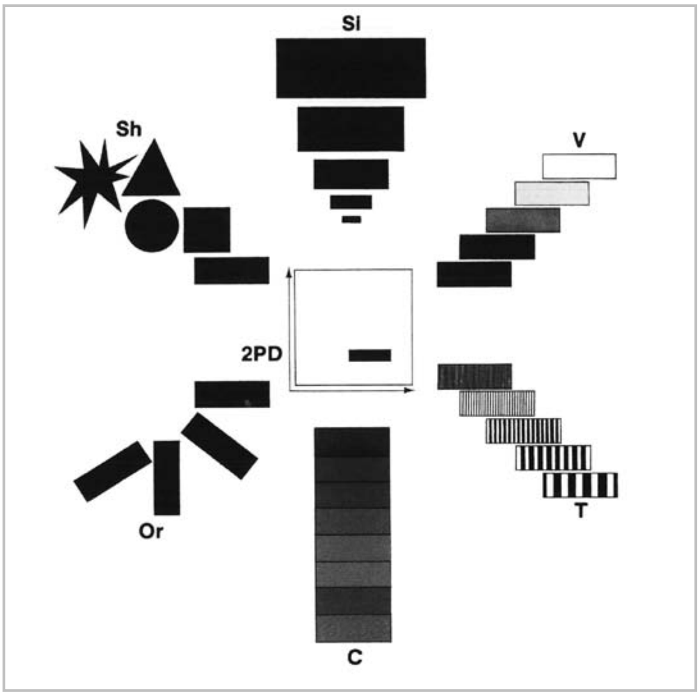


Figure 4.37: The palette of visual attributes from Bertin (1967/1983: 43).

By applying visual attributes to graphic objects, the represented information types may be categorised in the three overall information categories: nominal, ordinal, and quantitative. Bertin's theory (1983; 2000/01) outlines how each visual attribute relates to each information category [figure 4.38].

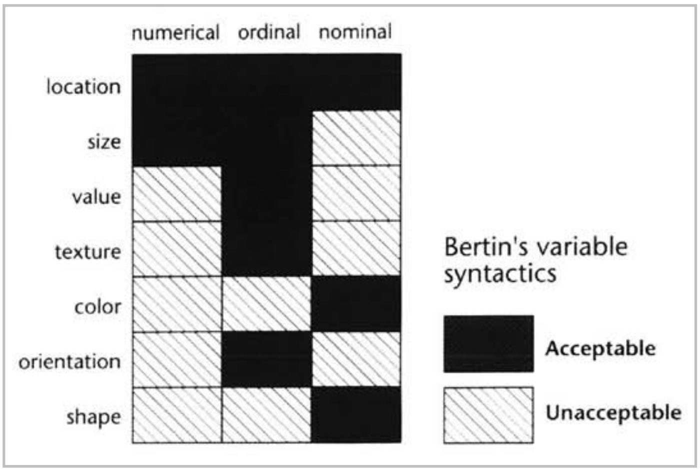


Figure 4.38: Relationship between visual attributes and overall information categories from MacEachren (2004: 272)

Engelhardt adapts Bertin's terminology and separates the seven attributes into 'spatial' – size, shape, position, and direction – and 'area fill' – colour and texture (2002: 25); forming the basis for 'spatial' and 'attribute-based' object-to-object relations [section 4.3.1, p. 105]. Coding variable 4 is limited to identifying the colour, texture, size and shape applied to arrows and circles or rectangular boxes which contain nodes. This focus was developed through the pilot analysis, and the decision to analyse text objects separately in relation to typographic attributes, *ie,* coding variable 5. Pictorial objects are excluded from Bertin's theory [section 4.4.2, p. 131], but here included as a type of shape, when identifying polysemic nodes and connectors.

This coding variable is related to the inconsistency indicator of graphic ineffectiveness. Here ineffective graphic tactics arise when different information types are visually associated through an attribute. Or if similar information types are visually dissociated through an attribute. Thereby this analysis differs from identifying polysemic nodes or connectors. The coding variable for visual attributes is applied to analyse one type of graphic object separately, where polysemic nodes or connectors are identified by taking combinations of graphic objects into account. The coding values for this coding variable are defined in relation to the three general tactics for categorising information as outlined by Bertin (1983; 2000/01) [figure 4.39].

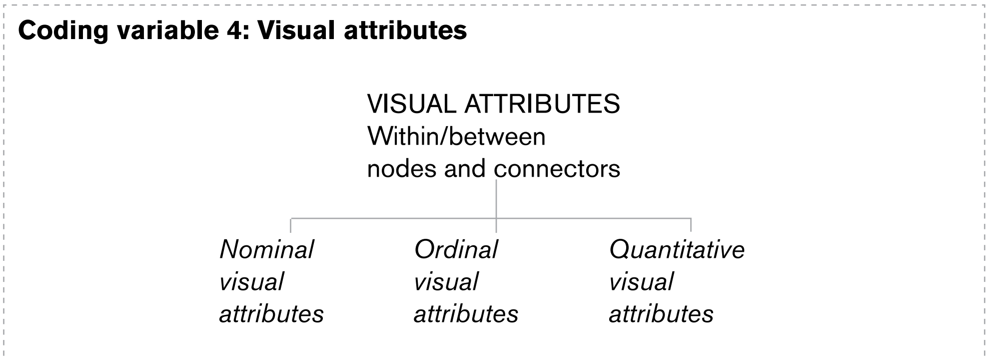


Figure 4.39: The three general graphic tactics for categorising information with visual attributes.

4.4.4.1 Nominal visual attributes: shape and colour

This coding value is applied to identify how shape and colour is used to create categories of information represented within and between the nodes and connectors. These may be sub-categories of one of the information types, *eg,* animals and plants within organisms. This is demonstrated by re-visiting a previous example.

Figure 4.40, was used in section 4.4.1.7 to demonstrate how the inclusion of a pictorial object in some nodes, *eg,* [a], resulted in applying the coding value 'multiple information types – polysemic'. Whilst the syntactic role is polysemic, the nodes are consistent when focusing solely on the container shapes and colour coding. Here the visual association created by similar shapes is consistent with the invariable information type, *ie,* matter, whilst the colour coding indicate different types of variable information, *eg,* material and organisms. This example demonstrates the potential complication created by different simultaneous interrelations between graphic objects and their graphic relations.

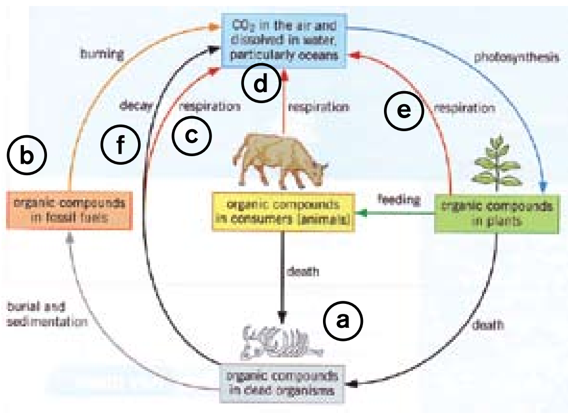


Figure 4.40: Diagram no 138

Graphic syntax aspect highlighted
Visual attributes:
Nominal visual attribute — colour.

The carbon cycle
From: Fullick and Fullick (2001b: 76)

Inconsistency is found within the arrows in the same diagram. Here a black colour attribute is applied to both death and decay, whereas other sub-categories of processes are distinguished by separate attributes. Inconsistency is also found between the nodes and connectors: the red container shape [b] represents 'organic compounds in fossil fuels'. The red arrows [c, d, e], firstly, do not exit the red coloured node [b], secondly, the arrows represent the process 'respiration', a biological process with little direct relation to fossil fuels. An additional note is that the colour coding further increased the puzzlement about the branching arrow [f] in this diagram; the red and black attributes emphasise the implicit nodal point, which is unlabelled.

Table 4.5 summarises the coding values for nominal visual attributes, figure 4.41 their relation to the indicators of graphic ineffectiveness which results in two general ineffective graphic tactics.

Coding values: Nominal visual attributes	**Identification**
Shape consistent	Shape attribute associates only elements which belong to the same information type.
Shape inconsistent	Shape attribute disassociates elements which belong to the same information type, or associate elements which do not belong to different information types.
Colour consistent	Colour attribute associates only elements which belong to the same information type.
Shape inconsistent	Colour attribute disassociates elements which belong to the same information type, or associate elements which do not belong to different information types.

Table 4.5: Coding values for nominal visual attributes based on Bertin (1983; 2000/01)

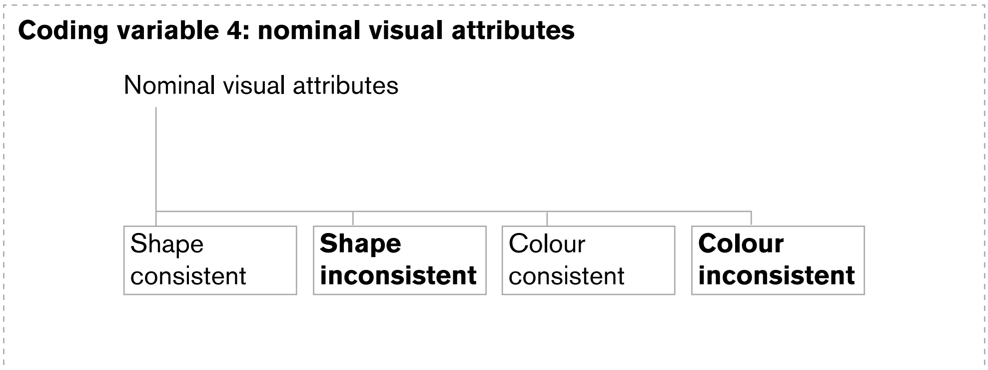


Figure 4.41: coding values for nominal visual attributes. Bold type indicates a value as a general ineffective graphic tactic.

4.4.4.2 Ordinal visual attribute: texture

Ordinal visual attributes also create nominal categories of the included information. Similar to the colour or shape visual attributes, texture may create ambiguity, if the information categorisation is inconsistent. Figure 4.42, for example, applies dashed arrow shafts to indicate 'bacterial action', as explained in the diagram's caption [a]. This part of the categorisation is consistent. However, the regular lined arrow shafts which here counts as a texture attribute include three unlabelled arrows [b, c, d] and one labelled a process, 'the Haber process' [e]. Thereby the application of the texture attribute is inconsistent. The texture attribute highlights an inherent complication when categorising information. The ordinal nature of texture creates a hierarchy in which it is suggested that there is 'less' bacterial action in a dashed arrow than there is 'Haber process' in the regular arrow. Table 4.6 summarises the coding values.

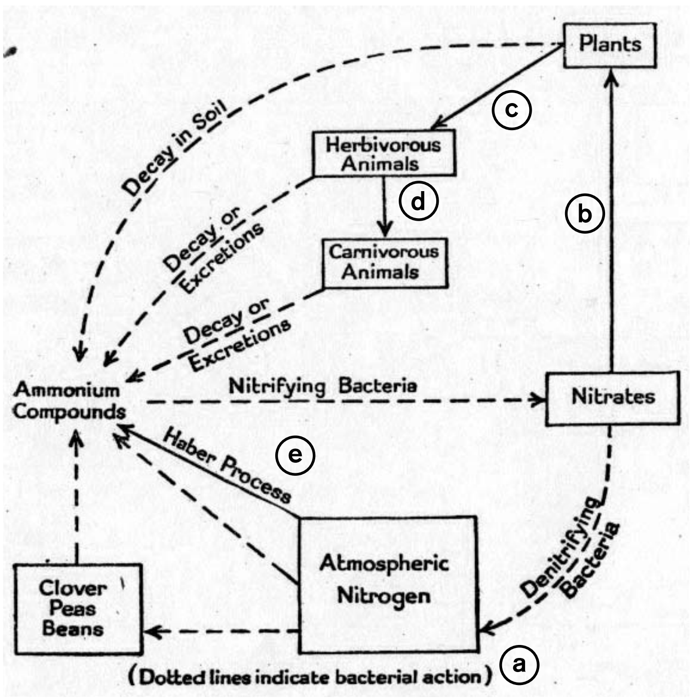


Figure 4.42: Diagram no 060

Graphic syntax aspect highlighted
Visual attributes:
Inconsistent application of texture attribute.

The nitrogen cycle
From: White (1939: 212)

Coding values: Ordinal visual attributes	Identification
Texture consistent	Texture attributes associate only elements which belong to the same information type. Hierarchy includes comparable information types.
Texture inconsistent	Texture attributes disassociate elements which belong to the same information type, or associate elements which do not belong to different information types. or Hierarchy includes incomparable information types.

Table 4.6: Coding values for ordinal visual attributes based on Bertin (1983, 2000/01)

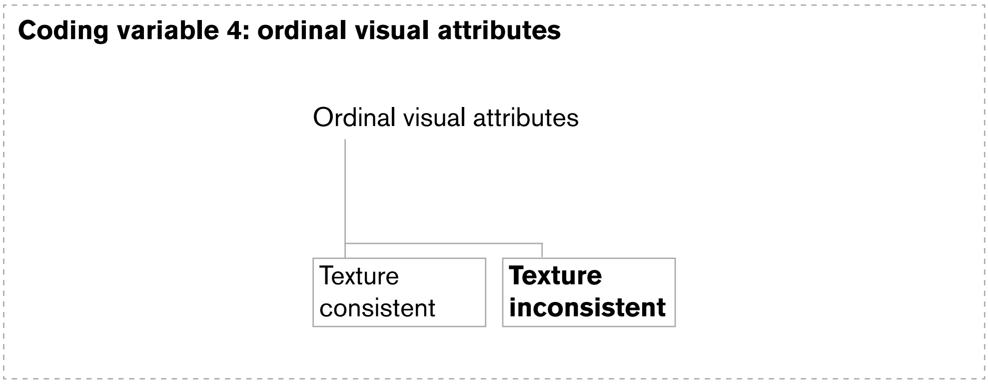


Figure 4.43: Coding values for ordinal visual attributes. Bold type indicates a value as a general ineffective graphic tactic.

4.4.4.3 Quantitative visual attributes: size

A quantitative attribute creates simultaneous nominal and ordinal categories of information within a diagram. This coding value does not evaluate the precision of size in relation to content proper quantities. Instead it is used to identify the nominal and ordinal categories created by different sizes within container shapes and width of arrow shafts. The length of arrow shafts is not analysed due to the nature of the content proper. Arrow lengths would here indicate time of a chemical transformation or transfer. With the limited space of a textbook page it would be impossible to indicate the time frame of photosynthesis compared to that of, *eg*, fossilisation.

Figure 4.42 [p. 144] demonstrated how the texture attribute creates a hierarchy whether consciously intended or not. Similar issues arise through the width of arrow shafts. For example, the arrows in figure 4.44 are of a similar shape but appear to be scaled according to the space available within the diagram. This indicates an inconsistent quantitative hierarchy in which there is, *eg,* half the quantity of 'protoplasm of animals' [a] going to 'ammonium compounds' [b] than there is 'nitrifying' [c] leaving the node.

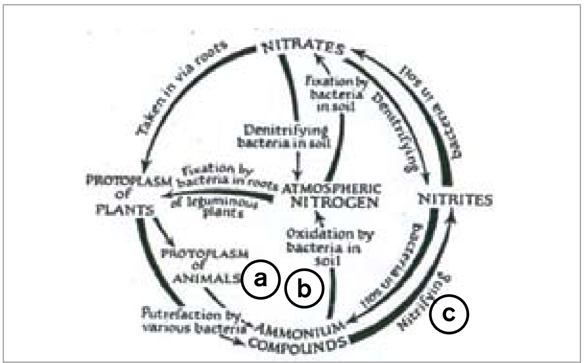


Figure 4.44: Diagram no 011

Graphic syntax aspect highlighted
Visual attributes: size
Arrows are inconsistently sized, based on scaling the arrow, rather than a significant content proper-attribute relation.

The nitrogen cycle
From: Graham (1937: 78)

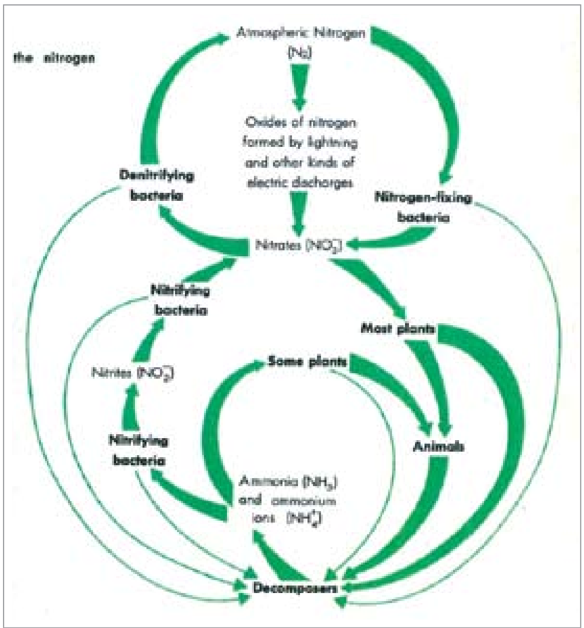


Figure 4.45: Diagram no 045

Graphic syntax aspect highlighted
Visual attributes: size
Arrows are inconsistently sized, because no indication is made of the elements related to each quantity.

The nitrogen cycle
From: Kolb (1963: 185)

Figure 4.45 applies size with more clarity, clearly indicating different quantities through size. However, the attribute is identified as inconsistent because the arrows are unlabelled. This creates confusion about what is being circulated and what elements there are 'more' of, *ie,* what the quantities relate to. Table 4.7 is an overview of the size coding value, and figure 4.46 summarises coding variable 4 in relation to the indicators of graphic ineffectiveness.

Quantitative visual attribute	Identification
Size: arrow width and container shapes Consistent	Size attribute associates only elements which belong to the same information type. Hierarchy includes comparable information types.
Size: arrow width and container shapes Inconsistent	Size attribute disassociates elements which belong to the same information type, or associates elements which do not belong to different information types. or Hierarchy includes incomparable information types.

Table 4.7: Coding values for ordinal visual attributes

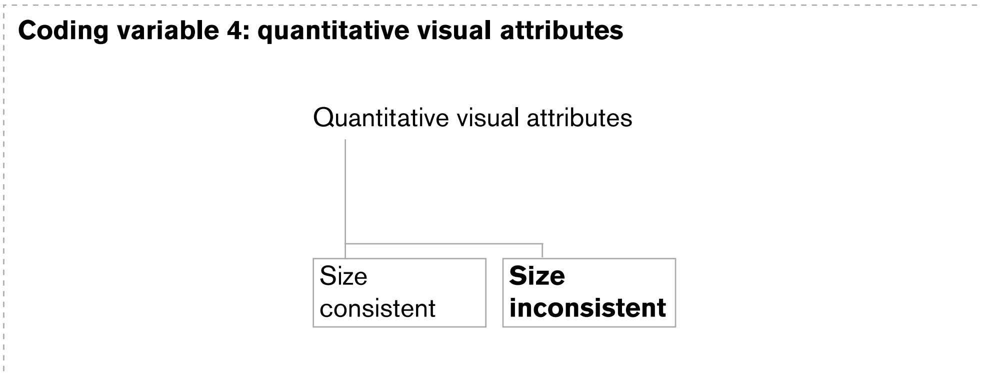


Figure 4.46: Coding values for quantitative visual attributes. Bold type indicates a value as a general ineffective graphic tactic.

4.4.5 Coding variable 5 – typographic attributes

Visual attributes applied to text objects are in this coding scheme analysed as typographic attributes, forming coding variable 5. Typographic attributes present a range of options for the designer when categorising information. Where instructional science has investigated the cognitive affects of, *eg,* including text labels in diagrams (*eg,* Sweller, 1988), typographic research contributes a well of knowledge on the detailing of text and how this may affect the information categorisation (Schriver, 1997; Hartley, 1994). The typographic attribute palette has several parallels to the visual attributes, based on common ground in Gestalt principles. Twyman (1982: 11) suggests a distinction between intrinsic and extrinsic typographic attributes, the first derived from the actual letter form, the second externally manageable by the designer. The specific characteristics are here listed in table 4.8, synthesised from Schriver (1997) and Twyman (1982).

Intrinsic and extrinsic typographic attributes	
Intrinsic	*Extrinsic*
Font: serif or san serif Slant: roman or italic Weight: semibold, bold, light *etc.* Size Case: upper/lower	Kerning Leading Space between blocks of text Colour Orientation

Table 4.8 Intrinsic and extrinsic typographic attributes synthesised from Schriver (1997) and Twyman (1982).

The typographic attributes may be applied to categorise information in ordinal, nominal, and numerical categories. Size is the only quantitative attribute. Ordinal categories are created by the intrinsic weight and case, and the extrinsic spatial features kerning, leading, and orientation. The remaining are nominal attributes. The pilot content analysis in this research enquiry identified the typographic attributes present in each diagram and whether a hierarchy is created within the nodes or connector labels. 14 different combinations of typographic attributes were found just in diagram group 1. Such combinations are taken into account when identifying polysemy in the nodes or connectors, *ie,* in coding variable 1. For coding variable 5 the analytical focus is narrowed to identify whether there is typographic distinction between text objects in nodes and connector, and whether the distinction is consistent.

4.4.5.1 Typographic attributes: node and arrow distinction

Text objects belonging to this coding value are identified by analysing across the diagram and noting whether typographic attributes are applied to distinguish nodes and connectors. This coding value is only identified in uncontained text objects and pictorial labels. The coding value is applied to note when no typographic distinction is used. Figure 4.47 demonstrates this general ineffective graphic tactic. There are eleven nodes and one arrow label

[a] applied without typographic distinction. This creates confusion about the syntactic role of the text objects, hence role of the related content proper elements as connected or connecting. The coding value is summarised in table 4.9, and integrated with the graphic ineffectiveness type in figure 4.48

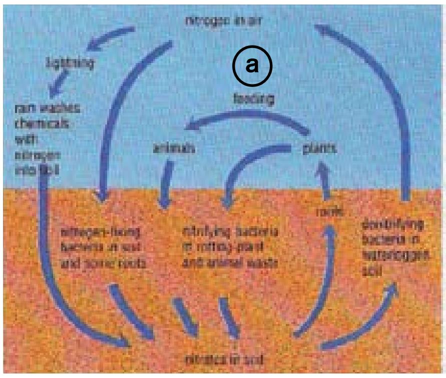


Figure 4.47: Diagram no 097

Graphic syntax aspect highlighted
Typographic attributes:
No distinction between arrow label and nodal typographic attributes

The nitrogen cycle
From: Taylor (1996: 69)

Typographic attributes	**Identification**
No distinction between nodal and connector text objects	Typographic attributes applied to arrow labels and nodes are similar.

Table 4.9: Typographic attributes coding values

Coding variable 5: typographic attributes

Typographic attributes

Non-distinctive nodes and arrow labels

Figure 4.48: Coding values for typographic attributes. Bold type indicates the value as a general ineffective graphic tactic.

4.4.6 Coding variable 6 – verbal syntax

The coding variables defined so far focus on different aspects of text objects when identifying the information categories in a diagram: the semantic content as information types, the text image relationship, arrow types, and typographic attributes. These coding variables are defined directly based on existing graphic syntax theory. Coding variable 6 complements this existing theory by revealing how information may be categorised using verbal syntax.

This final coding variable was identified and developed through the pilot analysis, and the 'multiple information types' coding value of coding variable 1 [section 4.4.1.7, p. 126]. Verbal syntax is in this thesis defined as a graphic syntax aspect because it creates association or dissociation between graphic objects in network diagrams. In turn this creates nominal categories of information. The association or dissociation is based on analysing the grammatical components of a text object and identifying whether recurring verbal patterns appear. Such patterns may be consistent or inconsistent within and between the nodes and connectors.

In figure 4.49 [next page] the nodes all contain 'noun(s) in noun'. Here this is identified as consistent verbal syntax – one recurring verbal pattern. Unfortunately this positive redundancy does not apply to the arrow labels which inconsistently applies either nouns [a], verbs [b], or both [c].

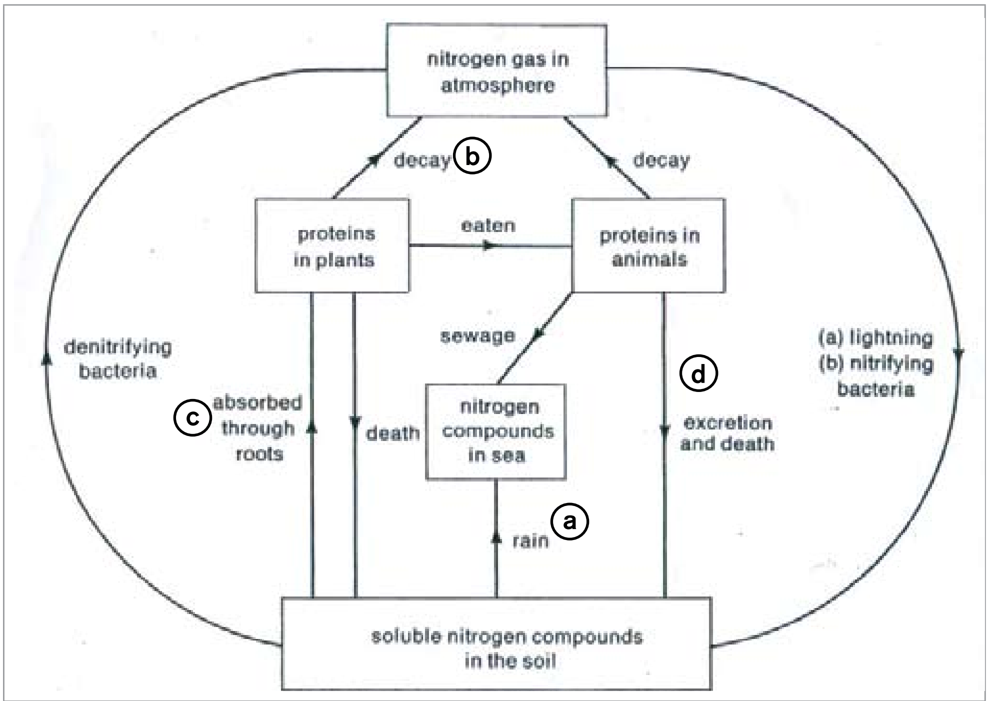


Figure 4.49: Diagram no 019

Graphic syntax aspect highlighted
Verbal syntax:
consistent nodes
inconsistent arrows

The nitrogen cycle
From: Henderson (1976: 356)

The inclusion of both nouns and intransitive and transitive verbs raises several interesting questions about verbal syntax and how it creates verbal linking between text objects; linking which creates additional information categories. It is beyond the scope of this research enquiry to identify the different verbal syntax arrangements in nodes and connectors which include multiple information types within the data set. However, this thesis contributes several findings in this area, by demonstrating a range of general ineffective graphic tactics within this graphic syntax aspect. These arise from the combination of coding values and are discussed in detail in section 5.7.3 [p. 200]. The coding variable includes three coding values, applied within nodes and connectors respectively.

4.4.6.1 Inconsistent verbal syntax

The first two coding values for verbal syntax are identified when a recurring pattern of verbal syntax appears within visually similar nodes and arrow labels respectively. This coding value has a crucial difference from the coding value for 'multiple information types – polysemic' [section 4.4.1.7, p. 126], which identifies patterns in the included information types. As an example, two visually similar nodes which include 'photosynthesis in plants' and 'bacteria in soil' are identified as 'multiple information types – polysemic' by the first coding value, but represent consistent verbal syntax. This highlights a critical interrelation between the two coding values because the consistent verbal syntax may reinforce the critical visual similarity between the polysemic nodes.

The third coding value in this coding variable identifies whether a single noun is applied in arrow labels, *eg*, 'rain' [a] in figure 4.49. This coding value relates to Richards' (1984) model of noun and verb spaces within diagrams [section 4.4.1, figure 4.15]. The coding value enables discussion – in section 5.7.3.1 [p. 202] – of how subject space-related verbal syntax may affect the identification of syntactic roles and arrow types. In figure 4.49, for example, the noun 'rain' [a] indicates movement between the two nodes, *ie,* a movement arrow indicating a chemical transfer. If the reader interprets a recurring pattern as 'noun label indicates movement between nodes', then 'excretion and death' [d] – two processes – appear to be moving too. Adding to this inconsistency is the verb 'decay' [b]; a conceptual link and a process which indicates a chemical transformation of 'protein in plants', *ie,* the source node. Table 4.10 and figure 4.50 summarise the coding values.

Coding values: verbal syntax	**Identification**
Inconsistent verbal syntax in nodes	Variation in verbal syntax across visually similar nodes
Inconsistent verbal syntax in arrow labels	Variation in verbal syntax across visually similar arrows
Noun arrow label	Arrow label includes a noun phrase.

Table 4.10: Visual attributes coding values

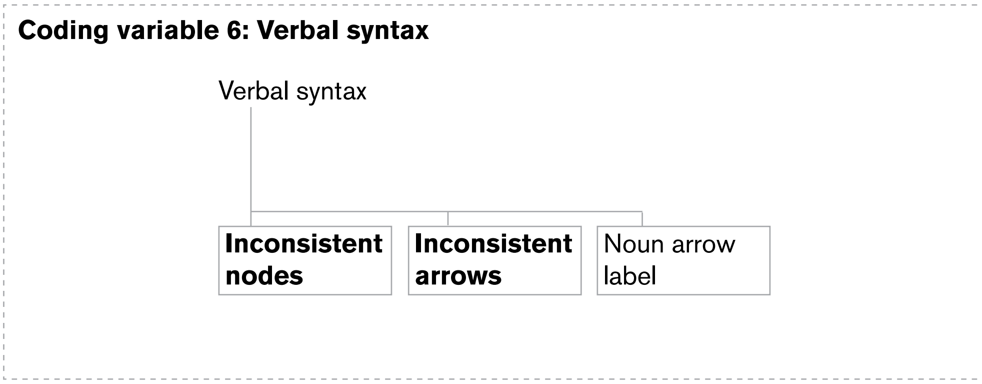


Figure 4.50: Coding values for verbal syntax. Bold type indicates a value as a general ineffective graphic tactic.

4.4.7 Overview of coding scheme

Figure 4.51 [A3 fold out] presents an overview of the complete coding scheme defined for this research enquiry. This figure serves the practical function of documenting the six coding variables and their coding values, which in turn facilitated the identification of information categorisation in existing visual output. Each coding value represents a graphic tactic. The coding values which represent general ineffective graphic tactics – applying to network diagrams in general – are marked with bold type. The graphic tactics – *ie,* coding values – which are 'neutral' may be part of an ineffective graphic tactic arising from the combination of coding values in a diagram. These are identified in chapter 5.

A general criticism of visual content analysis is that the method reduces an image to its parts, thereby overlooking their sum (Rose, 2007; Bell, 2003). The visual content analysis in this research enquiry is subject to these general limitations of the method. However, some 'sums of the parts' are taken into account – on a meta-level – through focusing on graphic objects in node and connector roles, and defining coding variables which identify the graphic 'object-to-object relations' within and between these two syntactic roles. Individual coding values thereby represent relationships between the diagram parts. The nature of the coding values, representing individual graphic tactics, also facilitates the second, conceptual function of the coding scheme. Here the coding scheme represents the design problem space investigated in this research enquiry.

A3 fold out: figure 4.51: Coding scheme

4.5 Coding scheme as design problem space

The coding scheme in this research enquiry serves a conceptual function enabled by defining coding values which represent individual graphic tactics. The definition of general ineffective graphic tactics within these – based on synthesising graphic syntax aspects, indicators of graphic ineffectiveness, and information types – here reveal the potential, general, theoretical complication when categorising information in a network diagram. In turn this represents general internal constraints of an ill-defined design problem.

4.5.1 An ill-defined design problem

The coding scheme here presented illustrates the designer's options when categorising six information types using six graphic syntax aspects, whilst aiming at reducing implicit and imprecise nodes, polysemy, and inconsistency in visual attributes, typographic attributes, or verbal syntax; all-in-all aiming at reducing the content proper ambiguity. Figure 4.51 visualises the design problem space, *ie,* the theoretical boundaries of the design problem investigated in this research enquiry. The coding variables here represent the sub-problems, each with a set of possible sub-solutions. The features which are taken into account when identifying each coding value represent the range of features – internal to the design problem – which the designer needs to take into account when deciding the sub-solutions. For example, to identify the 'multiple information types', coding value [section 4.4.1.7, p. 126] – and hence when applying the graphic tactic in practice – the type of graphic object, syntactic role, and information types included within the syntactic role needs consideration. These features thereby relate to both the options for each individual graphic tactic, and to the interrelations between graphic tactics.

The design problem space illustrated by figure 4.51 presents several complications through horizontal and vertical interrelations, *ie,* within and between graphic syntax aspects. Rowe (1987) [section 2.4.2.1, p. 43] described a complicated problem space arising from two options at each sub-problem. The coding variables included in the coding scheme for this research enquiry present between one and nine options for each sub-problem. Further complication is posed by the graphic tactics within each coding variable, which potentially affects the interrelated categories of information. These interrelations run within and between graphic syntax aspects due to the nonlinear nature of graphic syntax. Such interrelations were demonstrated, for example, by the different roles of text objects within categories of information in a diagram: the semantic content defines the information types, the text image relationships, and the arrow types. Further to this, the typographic attributes and verbal syntax may create additional association or dissociation, hence categories of information. Such intricate interrelations result in an ill-defined problem space. The designer of an ecological cycle network diagram therefore faces a complicated network of general design choices and decision-making.

Thereby the coding scheme defined for this research enquiry demonstrates the general potential complicated relationships between graphic objects, their graphic relations, and the way both of these create categories of the information represented in a network diagram. The next chapter identifies how the navigation of this ill-defined problem space by professional practice has manifested itself in visual output. Applying the coding scheme here reveals the information categorisation in existing ecological cycle network diagrams including the frequency of the general ineffective graphic tactics. These frequencies in turn allow for identifying additional – ecological cycle specific – ineffective graphic tactics, arising from different combinations of coding values. This adds texture to description of the problem space identified in this research enquiry which is an essential addition for integrating the research findings later. Identifying the general and cycle-specific internal constraints here reveal whether the occurrences of any ineffective graphic tactics - hence ambiguities - are affected by inherent complication in the design problem space in addition to the external constraints.

Summary

This chapter has presented the coding scheme for the visual content analysis, the method which is part of the *first research strand*.

The UK data set was arranged in six diagram groups, based on inclusion of shape-, text-, and pictorial objects.

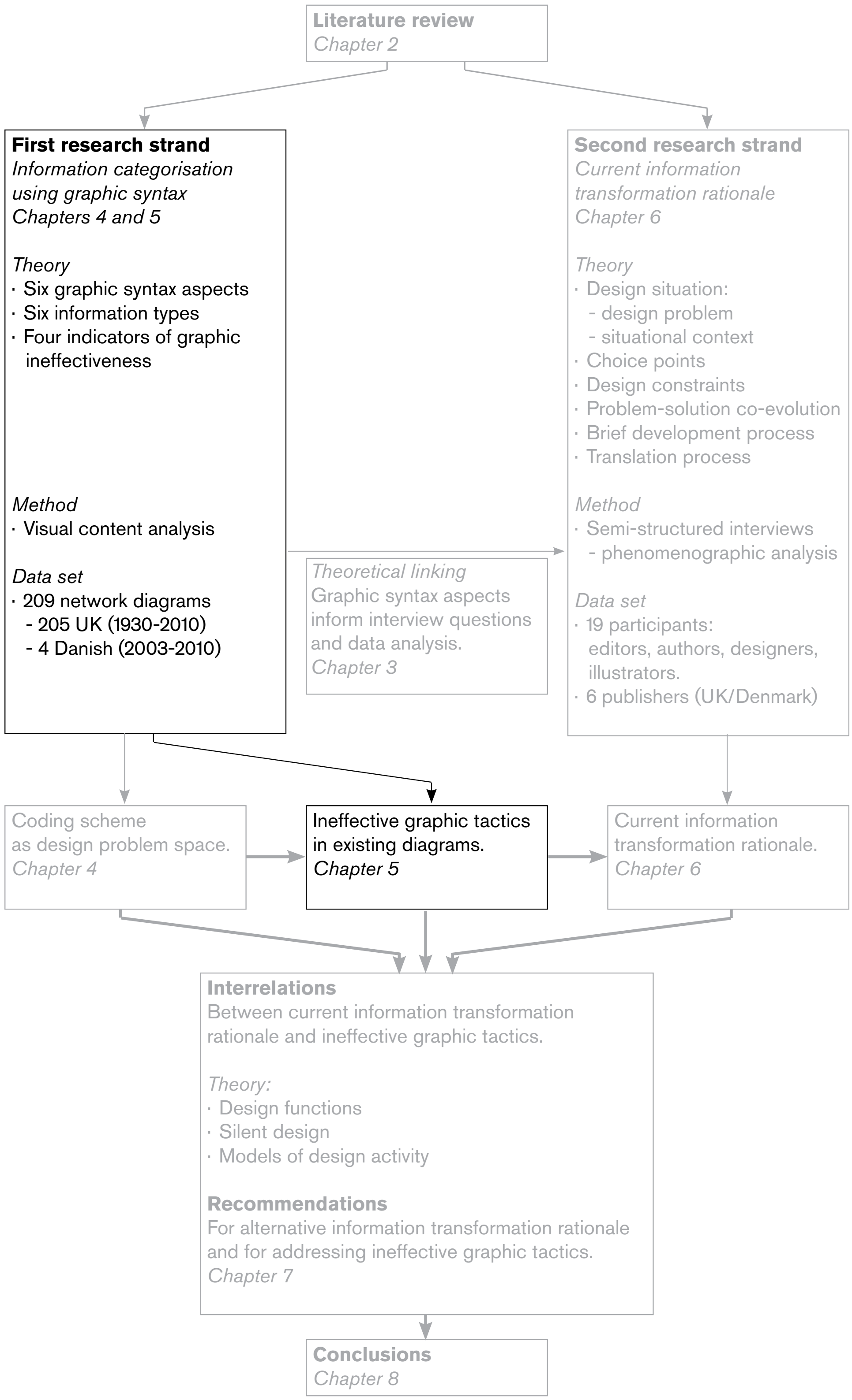
The coding scheme was defined to identify how information is categorised – nominally, ordinally, and quantitatively – within and between graphic syntax aspects in ecological cycle network diagrams.

The coding variables are formed by each of the graphic syntax aspects analysed, centred on identifying the information represented in node and connector syntactic roles, and sub-categories within and between these.

The sub-sets of coding values within each variable were formed by synthesising from the options within each graphic syntax aspect, indicators of graphic ineffectiveness, and general information types in ecological cycle network diagrams. The resulting coding values represent general 'neutral' or ineffective graphic tactics.

This chapter concludes, that when combined in the coding scheme, the coding values represent an ill-defined design problem space, in which complicated relations exist within and between graphic syntax aspects and their related graphic tactics.

5 Information categorisation in existing visual output


Literature review
Chapter 2
First research strand
Information categorisation using graphic syntax
Chapters 4 and 5
Theory
· Six graphic syntax aspects
· Six information types
· Four indicators of graphic ineffectiveness
Method
· Visual content analysis
Data set
· 209 network diagrams
- 205 UK (1930-2010)
- 4 Danish (2003-2010)
Second research strand
Current information transformation rationale
Chapter 6
Theory
· Design situation:
- design problem
- situational context
· Choice points
· Design constraints
· Problem-solution co-evolution
· Brief development process
· Translation process
Method
· Semi-structured interviews
- phenomenographic analysis
Data set
· 19 participants: editors, authors, designers, illustrators.
· 6 publishers (UK/Denmark)
Theoretical linking
Graphic syntax aspects inform interview questions and data analysis.
Chapter 3
Coding scheme as design problem space.
Chapter 4
Ineffective graphic tactics in existing diagrams.
Chapter 5
Current information transformation rationale.
Chapter 6
Interrelations
Between current information transformation rationale and ineffective graphic tactics.
Theory:
· Design functions
· Silent design
· Models of design activity
Recommendations
For alternative information transformation rationale and for addressing ineffective graphic tactics.
Chapter 7
Conclusions
Chapter 8

Contents

5 Information categorisation in existing visual output

5.1 Introduction

The outcomes from the visual content analysis in this thesis represent a meta-reflection on visual output from performing the design task in professional practice. The frequencies of coding values reveal the information categorisation in existing visual output, including the frequencies of general ineffective graphic tactics. From analysing these findings, this research has identified additional, ecological cycle specific, ineffective graphic tactics. This provides further detail of the potential theoretical complication in the design problem space investigated in this research enquiry.

5.1.1 Ineffective graphic tactics specific for ecological cycles

The visual content analysis in this research enquiry is guided by questioning what potential theoretical complications are involved when transforming information into an ecological cycle network diagram, and how information is categorised in existing visual output. The coding scheme here demonstrated general 'neutral' and ineffective graphic tactics, as represented by individual coding values, *ie,* the smallest units of analysis within the respective graphic syntax aspect. By defining the coding scheme as the design problem space investigated in this research enquiry, the general ineffective graphic tactics represent internal constraints generally applicable in network diagrams. Applying the coding scheme in analysis identified the frequencies of the coding values – *ie,* graphic tactics – and thereby the information categorisation in existing visual output. The frequencies of coding values here allow for identifying additional ineffective graphic tactics which are ecological cycle specific.

The additional ineffective graphic tactics relate to potential ambiguities arising from different combinations of coding values. These ineffective graphic tactics are demonstrated throughout this chapter, including their potential effects on the content proper message and the interrelated graphic tactics. From this emerges general effects of ineffective graphic tactics on the content proper message in ecological cycle network diagrams. Furthermore, the findings reveal how decisions within one graphic syntax aspect may affect the effectiveness of interrelated graphic syntax aspects. These effects – on the content proper message and other graphic syntax aspects – elucidate the level of complication within the design problem space investigated here.

Together, the outcomes presented in this chapter thereby unravel the design problem space. The outcomes demonstrate the level of complication posed when categorising up to six information types in an ecological cycle network diagram; and how the navigation of this ill-defined design problem space, within professional practice, has manifested itself in existing visual output. These findings are essential for the later integration of research findings [chapter 7]. Here knowledge of the potential theoretical complication reveals whether the occurrences of any ineffective graphic tactics - hence ambiguities - are affected by inherent complication in the design problem space in addition to the external constraints *ie,* features in the professional practice setting. In addition to this, the visual presentation of the analysis findings [table 5.1, p. 203] contributes a practical tool to current practitioners for reviewing the extent of ineffective graphic tactics in their own visual output. This is demonstrated in the sample of four Danish ecological cycle network diagrams.

5.1.2 Presentation of findings in this chapter

The findings from each coding variable, *ie,* graphic syntax aspect, are presented in individual sections [section 5.2-5.7] which include general ineffective graphic tactics and ineffective graphic tactics which may arise from combinations of coding values. The effects on the content proper message is highlighted throughout these sections, as are interrelations between different coding variables and values. This elucidates how decisions within one graphic syntax aspect may affect the effectiveness of interrelated graphic syntax aspects.

Following this, a section presents an overview in tabular form of the ineffective graphic tactics found within the UK data set [section 5.8, p. 203]. Then the table is applied to analyse the Danish data set [section 5.8.1.3, p.

210]. In the final section, the analysis findings are discussed in relation to the design problem space. Throughout the chapter, the six analysis groups formed in the UK data set are referred to as G1-G6.

5.2 Coding variable 1 – node and connector syntactic roles

This coding variable was applied to identify, firstly, implicit and imprecise nodes, and secondly, which of the six information types appear in explicit node and connector roles within the data set. The coding values for explicit nodes and connectors form the core of the visual content analysis in this research enquiry. The frequencies of these coding values identify how information types are included in the ecological cycle network diagrams as connected or connecting – the two fundamental categories of information in a network diagram – and whether the nodes or connectors are polysemic. This lays the foundation for identifying – through the five remaining coding variables – how sub-categories of information are created within and between the nodes and connectors.

5.2.1 Information categorisation in nodes and connectors

Coding variable 1 includes eight coding values which represent individual general ineffective graphic tactics [Section 5.2.2, p. below]. These coding values relate to three indicators of graphic ineffectiveness: implicit nodes, imprecise nodes, and polysemy. Polysemy may arise from combinations of coding values for explicit nodes and connector within a diagram. This underlines the importance of precision when categorising information using this basic graphic syntax aspect. This importance is further demonstrated by identifying an additional four ineffective graphic tactics arising from combinations of coding values [Section 5.2.3, p. 169].

5.2.2 General ineffective graphic tactics within nodes and connectors

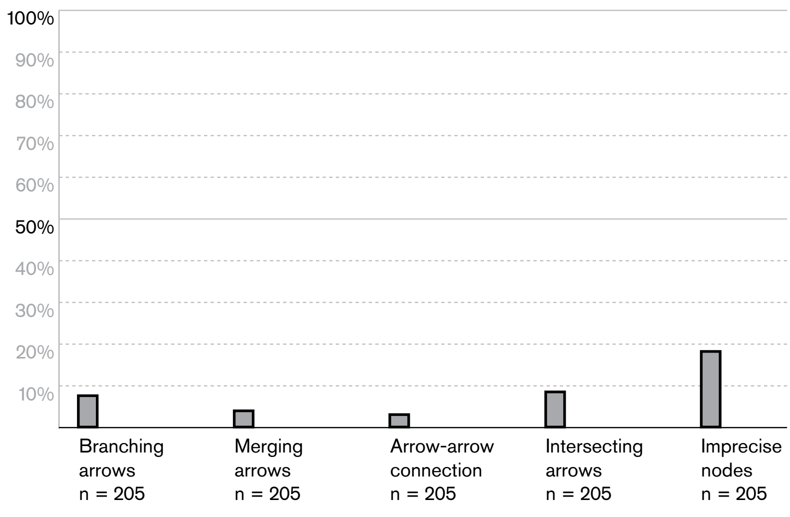
This sub-section presents the frequencies of the coding values which represent general ineffective graphic tactics within nodes and connectors:

- Implicit nodes [Section 5.2.2.1, p. 167]
  - branching arrow
  - merging arrows
  - arrow-arrow connection
  - intersecting arrows

- Imprecise nodes [Section 5.2.2.1, below]
  - imprecise relative spatial positioning
- Explicit nodes and connectors [Section 5.2.2.2, p. 167]
  - unlabelled pictorial object
  - unlabelled arrow
  - multiple information types – polysemic

5.2.2.1 Implicit and imprecise nodes

Implicit nodes are general ineffective graphic tactics in which the spatial positioning of arrows, in relation to other graphic objects, results in the appearance of an – intentional or unintentional – nodal point. Each general ineffective graphic tactic was demonstrated in sections 4.4.1.1-7 when defining the coding values. This illustrated how an implicit or imprecise node may create confusion about the nature of the implicit content proper element and its role within the cycle. The five coding values stand apart from the rest of the coding scheme by being identified within the data set as a whole, rather than the six diagram groups (G1-G6). The most frequent of these general ineffective graphic tactics are instances of imprecise nodes, which occur in 19% of the data set [Bar chart 5.1].

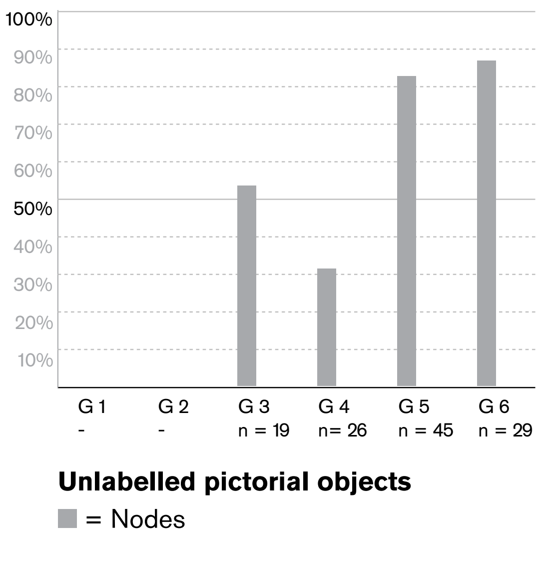


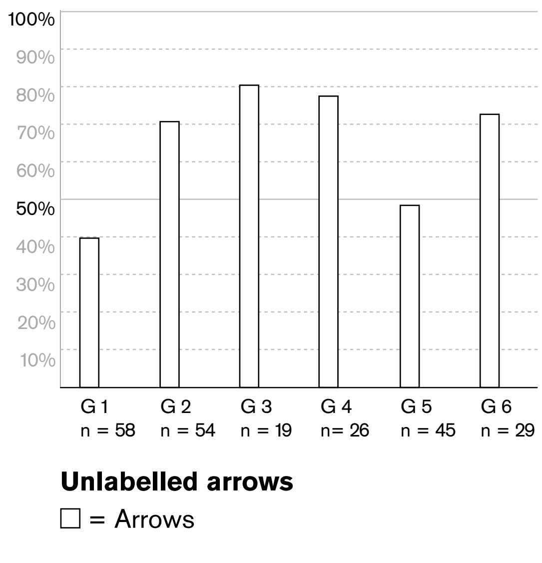
Bar chart 5.1: frequency of coding values for implicit and imprecise nodes.

An implicit or imprecise node creates ambiguity about the nature of the hidden connected content proper element. Imprecise nodes also create ambiguity about the role of the included elements as connected or connecting. All five coding values thereby highlight the need for clear intentions with all included objects and information within a network diagram. These frequencies are not included in later identification of polysemic syntactic roles [5.2.3.4, p. 174], which are identified within explicit – *ie,* intended – nodes only. The coding values for explicit nodes themselves include three general ineffective graphic tactics: unlabelled pictorial objects, unlabelled arrows, and 'multiple information types – polysemic'.

5.2.2.2 Unlabelled pictorial objects and arrows

Unlabelled pictorial objects and arrows represent single instances of polysemy. Such instances leave the reader to interpret the included information. This may create ambiguity about the correlating content proper element. Single instances of unlabelled pictorial objects are most frequent within diagrams that include integral metric spaces [bar chart 5.2]. However, it is concerning to also find instances of this coding value in 31%-53% of the diagrams in G3 and G4. Similarly concerning is that unlabelled arrows appear at consistently high frequencies, between 40%- 80% in all diagram groups [bar chart 5.3].



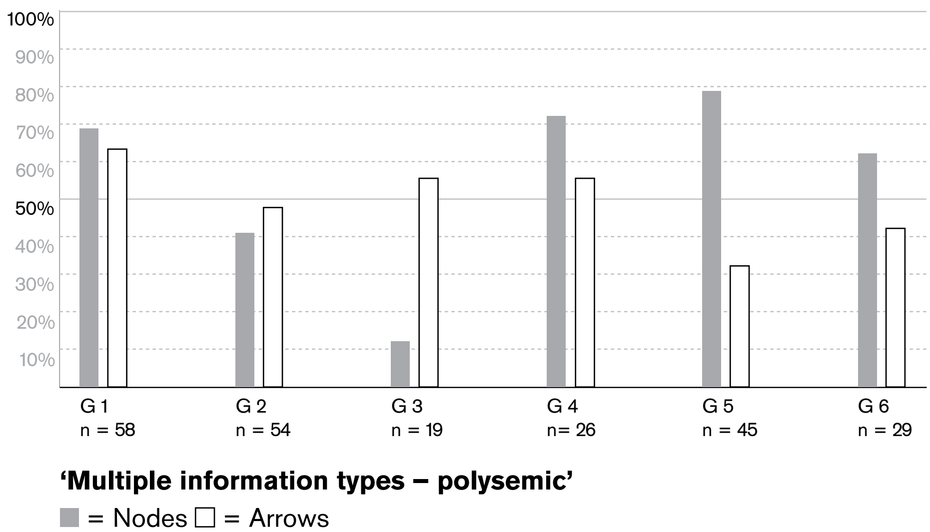


Bar chart 5.2: frequency of coding values for unlabelled pictorial objects.
Bar chart 5.3: frequency of coding values for unlabelled arrows.

These two coding values are related to several others. Unlabelled pictorial objects also affect the consistency of text image relationships within this type of graphic objects [section 5.3, p. 179]. When combined with other coding values in a diagram, the unlabelled graphic objects also contribute to polysemy within the nodes or connectors. The frequencies of these two coding values are therefore included when discussing polysemic syntactic roles in section 5.2.3.4 [p. 174].

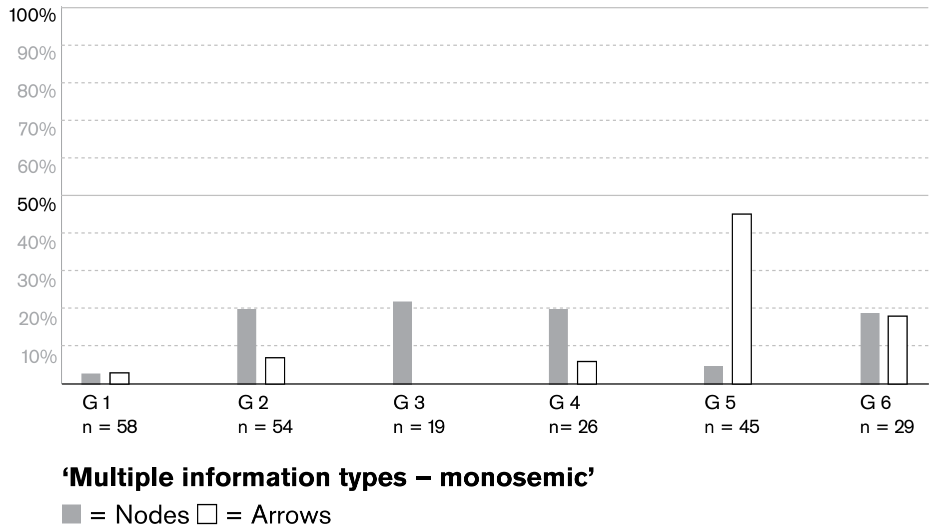
5.2.2.3 Multiple information types – polysemic

This third general ineffective graphic tactic – within explicit nodes – is identified when two or more nodes include multiple information types [section 4.4.1.7, p. 126]. The 'multiple information types – polysemic' coding value has a high frequency within the data set [bar chart 5.4]. It was identified within the nodes in more than half of the diagrams in four of the diagram groups, and within the connectors in 32%-63% of all six diagram groups.



Barchart 5.4: Frequency of coding value: 'Multiple information types – polysemic'

Generally, the frequency of this coding value suggests low priority – or awareness – for creating positive visual redundancy when combining multiple information types within nodes or connectors in existing ecological cycle network diagrams. This in turn creates ambiguity about the nature and role of the included elements. Few diagrams utilise the graphic tactic for multiple information types effectively. This is demonstrated by the frequency of the coding value for 'multiple information types – monosemic' [bar chart 5.5].



Bar chart 5.5: Frequency of coding value: ‘multiple information types – monosemic’.

The two coding values for ‘multiple information types’ relate to several other graphic tactics. Monosemy and polysemy were here identified by taking the combination of graphic objects and their attributes into account. The sub-categories of information created by these other graphic syntax aspects are identified separately using the five remaining coding variables. The frequencies of the coding values for multiple information types also relate to identifying polysemy within nodes and connectors, which may arise from a combination of coding values within explicit nodes and connectors.

5.2.3 Ineffective graphic tactics arising from a combination of coding values within explicit nodes and connectors

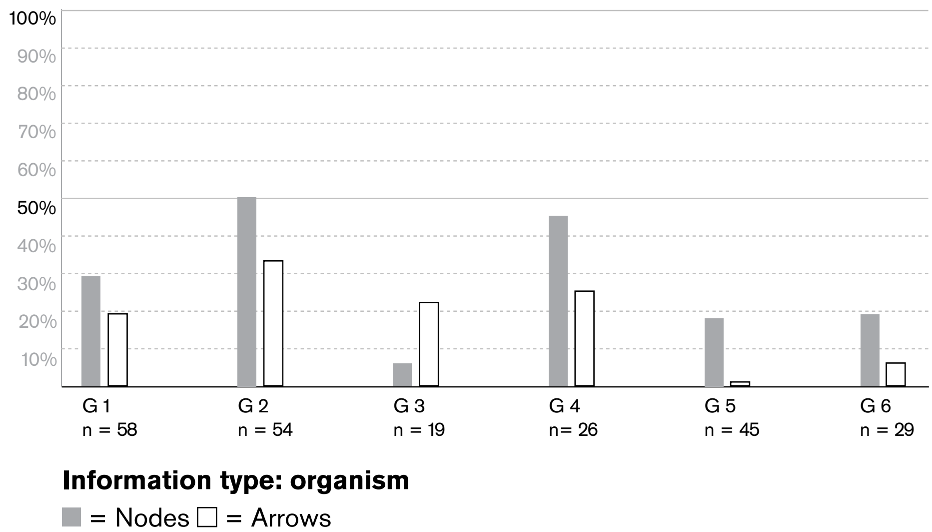
Ineffective graphic tactics may arise from different combinations of coding values within a diagram. These are identified within this coding variable by analysing, firstly, the frequencies of coding values described as ‘neutral’ in chapter four; secondly, by analysing their combination with the coding values which represent general ineffective graphic tactics. These additional ineffective graphic tactics are thereby cycle specific. The ‘neutral’ coding values within coding variable 1 – node and connector syntactic roles – each represent one of the six information types. These coding values are based on the semantic definition summarised in appendix 5. The coding values were applied to identify which instances of singular information types are included in nodes and connectors within the ecological cycle network diagrams in the data set.

The additional analysis here identifies five ineffective graphic tactics arising from combinations of the coding values:

- Categorising organisms in connector roles [section 5.2.3.1, p. 170]
- Excluding matter from connector roles [section 5.2.3.2, p. 171]
- Categorising process in connector roles [section 5.2.3.3, p. 172]
- Polysemy within explicit syntactic role [section 5.2.3.4, p. 174]
- Exclusively unlabelled connectors [section 5.2.3.4, p. 174]

5.2.3.1 Categorising organisms in connector roles

Generally, organism, matter, and material are the most frequent coding values identified in the nodes within the data set, process is by far the most frequent in connectors. The frequency of the organism coding value in arrow labels [bar chart 5.6] reveals an ineffective graphic tactic deriving mainly from nitrogen cycle diagrams. Several diagrams include the nitrogen cycles' different bacteria in arrow labels. If these arrows are read as movement arrow types, then the relating content proper message is that bacteria – rather than matter – are in circulation. This ineffective graphic tactic thereby relates directly to the arrow type coding variable [section 5.4, p. 183].



Bar chart 5.6: Frequency of coding value for organism information type.

This ineffective graphic tactic is demonstrated by figure 5.1 [next page]

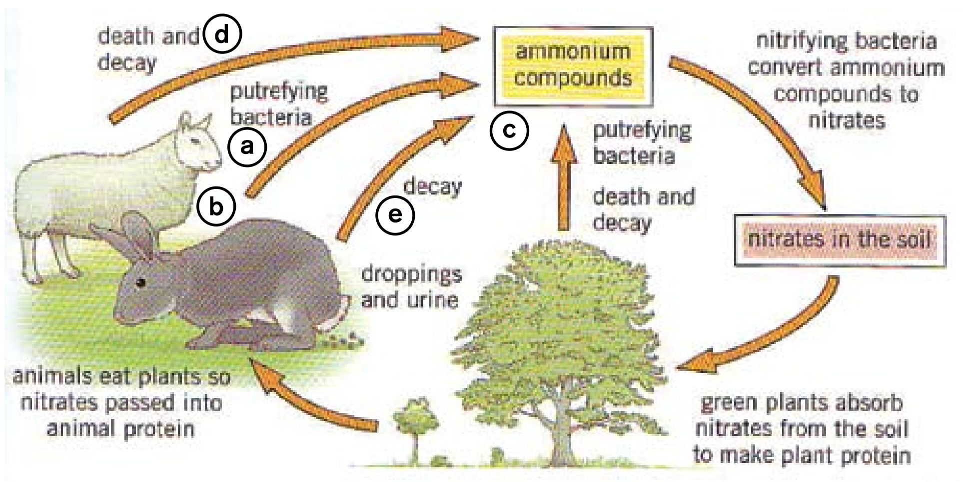


Figure 5.1: Diagram no 139

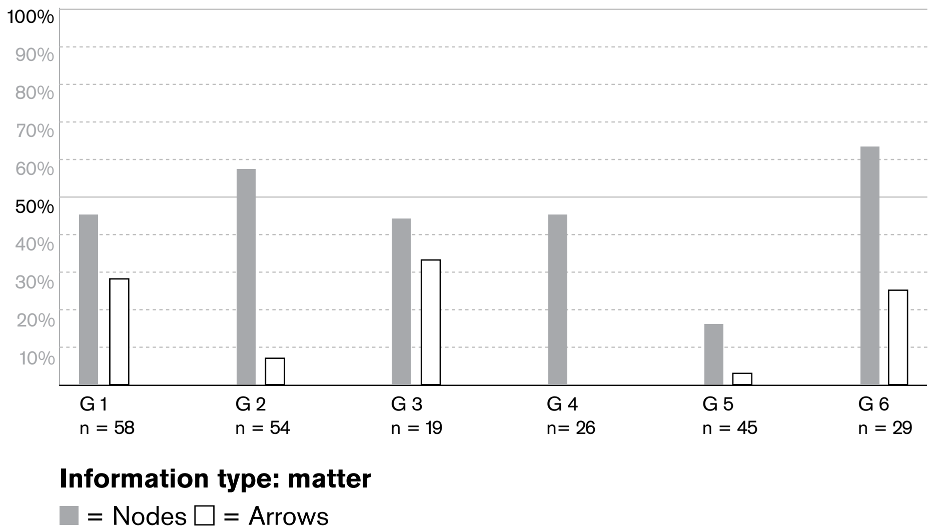
Graphic syntax aspect highlighted
Categorising organism in connector roles:
If the arrow is read as 'movement between' arrow, organisms appear as circulating.

The nitrogen cycle
From: Fullick and Fullick (2001b: 66)

In figure 5.1 the arrow [a] going from the pictorial node of a sheep and rabbit [b] represents 'putrefying bacteria'. As such, the bacteria appear to be moving between the animals and ammonium compounds [c], rather than serving as an agent for the chemical transformation process 'decay'. Decay is instead added to the two neighbouring arrows [d and e]. Curiously the sheep appears to both 'die' and 'decay' whereas the rabbit is transformed by 'decay' only. This ineffective graphic tactic highlights the need for precisely categorising process agents within an ecological cycle network diagram and visually distinguishing them from other types of content proper elements. The finding is interesting compared to the relatively low frequency of the matter coding value in connector roles.

5.2.3.2 Excluding matter from connector roles

Bar chart 5.6, above, revealed how several ecological cycle network diagrams include organisms as potential circulating elements. The concern about this pattern in information categorisation is increased by finding a low frequency of the matter coding value in connectors, compared to nodes [bar chart 5.7, next page]. This ineffective graphic tactic also relates directly to the arrow type coding variable and movement arrows [section 5.4, p. 183].

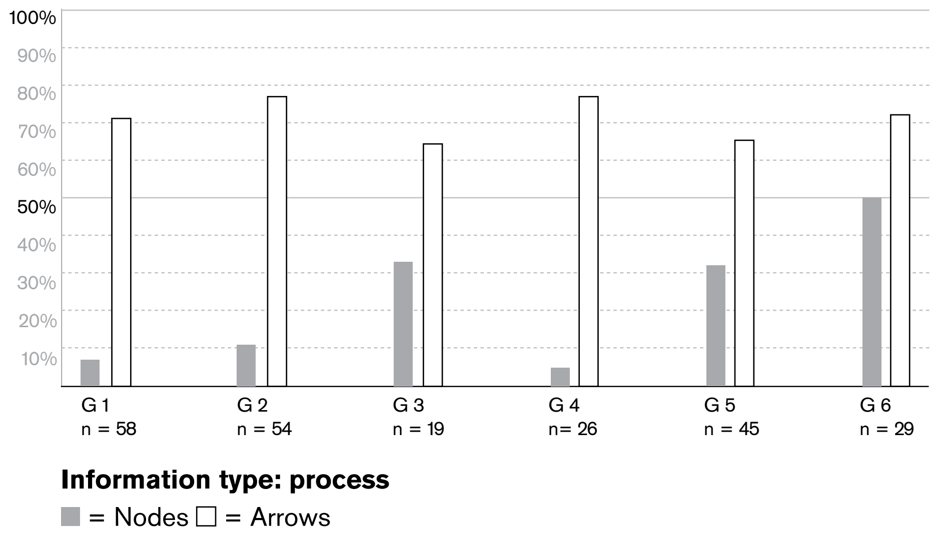


Bar chart 5.7: Frequency of coding value for matter information type.

Within the data set, the matter information type frequently appears as a stored element, in the syntactic 'passive' nodes, rather than an 'active' circulating element in arrow labels. This increases the ambiguity about what actually circulates between the connected elements and how circulation of matter provides the crucial linking. This finding also elucidates an inherent conflict when transforming a dynamic and organic content proper subject into a static printed diagram of which some parts are syntactically 'passive'. Where matter generally is represented as a syntactic 'passive' element, the process information type is by far the most common syntactic 'active' – *ie,* connecting – element found in the data set.

5.2.3.3 Categorising process in connector roles

Representing processes in arrow labels relates directly to the arrow type coding variable [section 5.4, p. 183] and conceptual linking, *ie,* chemical transformation. This is the most common information type in explicit connector roles [bar chart 5.8, next page]



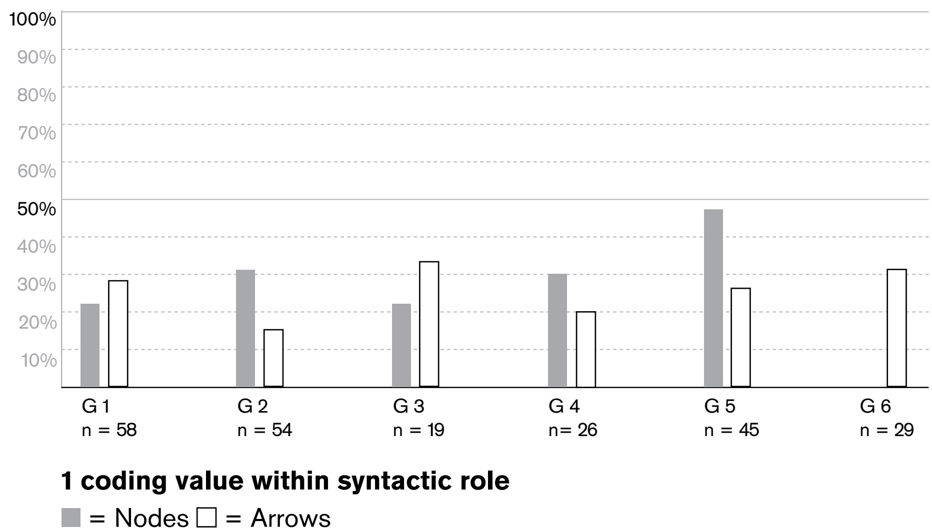
Bar chart 5.8: Frequency of coding value for process information type.

This graphic tactic is ineffective – within the specific context of ecological cycles – if the physical position of the element is interpreted as literal by the reader. In this case the process may appear dislocated from its related element. This is particularly common in carbon cycles when 'photosynthesis' is visually represented by an arrow between a 'plant' and 'atmosphere' node [*eg*, figure 4.20, p. 120]. Photosynthesis may then potentially be read as happening mid-air. This finding highlights the challenge posed by the need to accommodate both chemical transfers and transformation in the same diagram; *ie,* processes that take place both within and between other elements. Exam specifications for the 14-18 years age groups exclude explicit distinction between chemical transfers and transformations. Where this exclusion simplifies the information hierarchy in the verbal source content, it may increase the complication when categorising the information using graphic syntax.

The frequencies of the remaining 'neutral' coding values – material, pool, and energy and force – are summarised in appendix 6. The energy and force and pool coding values appear mainly in water cycles – as represented, *eg,* by 'wind', and 'the sea'. Their status as ineffective graphic tactics depend on the combination of coding values within a diagram and relate to polysemy within the syntactic roles.

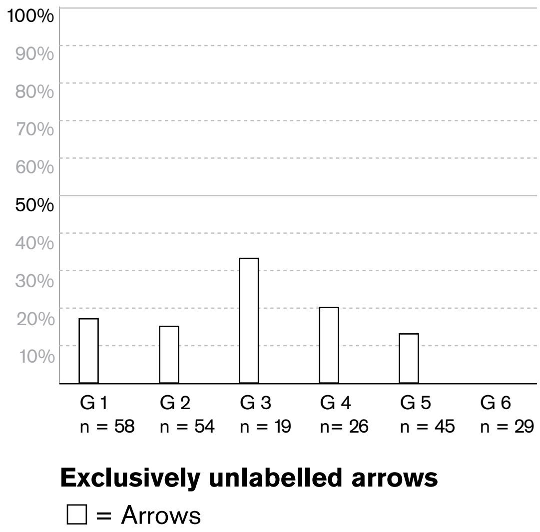
5.2.3.4 Polysemy within explicit syntactic roles

The combinations of coding values within diagrams reveal whether polysemy occurs within visually similar – explicit – nodes and connectors in a diagram. One way to avoid polysemy is to apply a single coding value only. However, the frequencies for only one type of coding value within visually similar nodes and connectors include several individual ineffective graphic tactics [bar chart 5.9]. These arise if the sole coding value is 'multiple information types – polysemic', unlabelled pictorial objects, unlabelled arrows, organisms in connector roles, matter excluded from connectors, or processes in connector roles. Thus avoidance of polysemy, in relation to the syntactic role across a diagram, may result in other ineffective graphic tactics. This illustrates the inherent theoretical complication when categorising information in an ecological cycle network diagram.



Bar chart 5.9: Frequency of diagrams which include 1 coding value within each syntactic role.

No diagram includes solely unlabelled pictorial objects, however, the frequency for connectors in G2 and G3 [bar chart 5.9] derives from diagrams which include exclusively unlabelled arrows [bar chart 5.10].



Bar chart 5.10: Frequency of diagrams with exclusively unlabelled arrows.

When including more than one coding value within the nodes or connectors, the designer may use the three types of graphic objects – text, shape and pictorial object – to visually categorise the information, as well as visual and typographic attributes[1]. The majority of diagrams in the data set combines between one and four coding values within nodes or connectors. These frequencies are summarised in appendix 6. The different coding values are rarely visually dissociated within these diagrams; only 18 diagrams in G1, and one in each of the other diagram groups avoids polysemic syntactic roles.

If visual association or disassociation is not observed – between different information types – the syntactic role is polysemic and represents an ineffective graphic tactic. The upper case nodes in figure 5.2, for example, combine organism, 'plants' [a], and matter, 'atmospheric carbon dioxide' [c]. Figure 5.2 also includes an example of 'multiple information types – monosemic', 'putrefaction by various bacteria' [d]. This is a node, but typographically similar to the arrow labels – *ie,* lower case – hence visually associated within the nodes and connectors. Node [b], meanwhile, is an

1 The coding values considered for identifying polysemic syntactic roles are: those for each of the six single information types (organisms, matter, material, pool, process, energy and force), unlabelled pictorial object, unlabelled arrow, multiple information categories – polysemic, multiple information categories – monosemic. The shape of containers is not taken into account if it appears determined by the amount of text contained.

example of an imprecise node, identified by taking the information type into account. 'Combustion' is here identified as an arrow label.

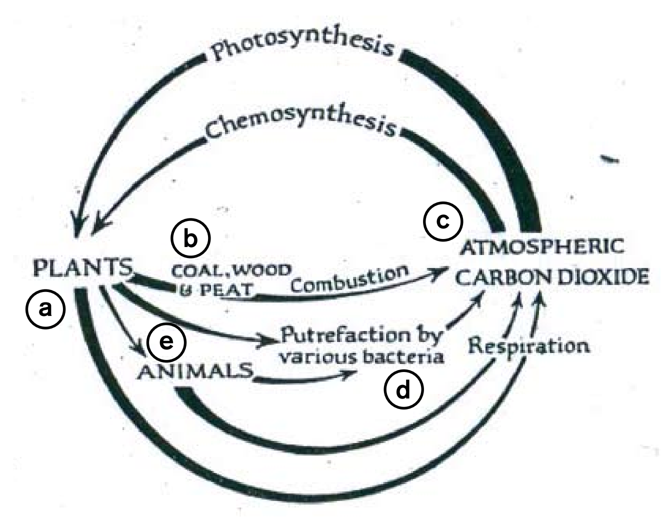


Figure 5.2: Diagram no 010

Graphic syntax aspect highlighted
Node-connector:
Polysemy: Combining more than one information type within visually similar nodes.
Upper case nodes – same size: *organisms* 'plants' [a], and *matter* 'atmospheric carbon dioxide' [c].

The carbon cycle
From: Graham, A (1937: 20)

As a result of the polysemic nodes, the nature of connected elements in figure 5.2 is ambiguous. The inclusion of unlabelled arrows here increases the ambiguity because the respective role of each element and their interrelations are implicit. For example, combining matter and organisms in nodes with unlabelled arrows creates ambiguity about chemical transformation and transfers within the sequence: 'plants' [a] either move to, or are transformed into, 'animals' [e]. Because no 'death' is indicated, 'animals' are – presumably – alive when they reach the element in the next node [d]. These live animals are, apparently, putrefied by bacteria [d] and move to, or are transformed into, atmospheric carbon dioxide [c]. This example illustrates how single instances of polysemy – each unlabelled arrow – interact with polysemy within the nodes. This results in a diagram which needs close scrutiny to unravel that included elements have different natures and different interrelations; hence the logic of the linking sequence.

It is beyond the scope of this research enquiry to identify frequencies of different combinations of coding values between nodes and connectors. However, figure 5.3 provides an interesting example of such combination – here four coding values within the nodes and four within connectors – resulting in severe ambiguity about the nature of elements in the nitrogen cycle.

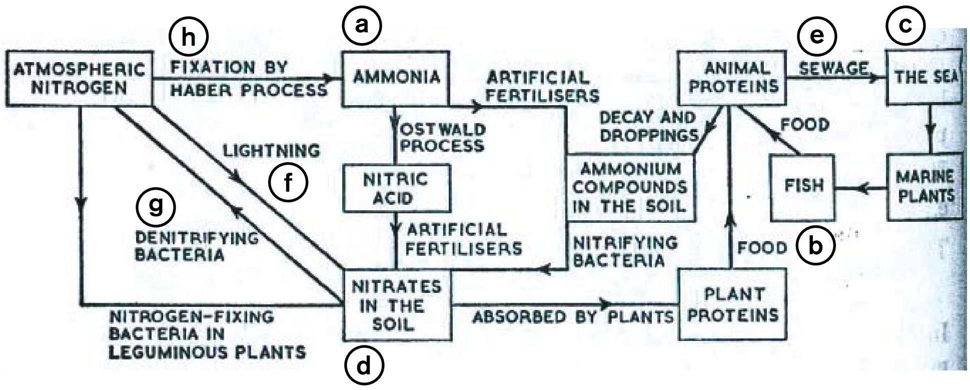


Figure 5.3: Diagram no 081

Graphic syntax aspect highlighted
Polysemic syntactic roles:
Contained nodes include:
Matter, 'ammonia' [a], *organism*, 'fish' [b], *pool*, 'the sea' [c], multiple information types – monosemic, *eg,* 'nitrates in the soil' [d]. (Shape of containers is discounted, as it appears determined by amount of text).

Connectors:
Material 'sewage' [e], process 'lightning' [f], organisms 'denitrifying bacteria' [g], multiple information types – polysemic, *eg,* 'fixation by Haber process' [h].

The nitrogen cycle
Hicks (1970: 442)

The nodes include:

a] *matter* 'ammonia',

b] *organism* 'fish',

c] *pool* 'the sea',

d] 'multiple information types – monosemic', *eg*, 'nitrates in the soil'

The connectors combine:

e] *material* 'sewage',

f] *process* 'lightning',

g] *organisms* 'denitrifying bacteria'

h] 'multiple information types – polysemic', *eg*, 'fixation by Haber process'.

This diagram provides an extraordinary challenge for a reader trying to disambiguate the nature of connected and connecting elements. Denitrifying bacteria [g] may, for example, be moving in the opposite direction of lightning [f], from 'nitrates in the soil' to 'atmospheric nitrogen'. Meanwhile, 'fish' [b] provides 'food' for 'animal proteins' [e], from which 'sewage' moves to 'the sea'; 'the sea' itself appears to be moving towards 'marine plants' [c]. Such complicated information categorisation highlights the importance of understanding the basic syntactic role of nodes and connectors in network diagrams. Without respecting this principle and distributing the information types precisely, a highly illogical – and rather puzzling – ordered sequence may occur. Part of this confusion is caused by the nature of different arrow types, which is discussed in section 5.3, [next page]

Coding variable 1 was applied to identify the fundamental categorisation of information into connected and connecting elements. The remaining five coding variables now help unpack the information categorisation from the perspective of each other as graphic syntax aspects. This reveals how sub-categories are created within and between nodes and connectors.

5.3 Coding variable 2 – pictorial objects

This coding variable focuses on sub-groups of nodes created by applying pictorial objects. The coding values here related to the information included in pictorial object labels and were applied to identify, firstly, the text image relationship between individual pictorial objects and their labels, and, secondly, the consistency of these relationships within the diagrams [section 4.4.2, p. 131]. Only G3-G6 include pictorial objects (n=19/26/45/29).

5.3.1 Information categorisation using pictorial objects

Coding variable 2 includes one general ineffective graphic tactic as a coding value – inconsistent text image relationship – which relates to the inconsistency indicator of graphic ineffectiveness and the aim of creating positive redundancy when categorising information within the same type of graphic objects. The coding variable was also used to identify polysemy within the pictorial objects which may arise from combinations of coding variables in a diagram [5.3.3, p. 181].

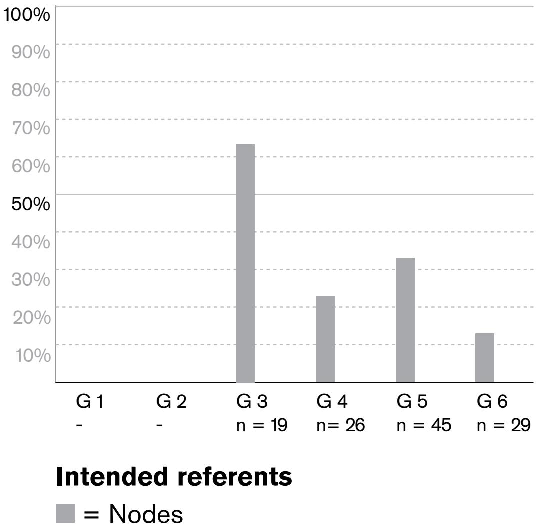
5.3.2 General ineffective graphic tactics within pictorial objects

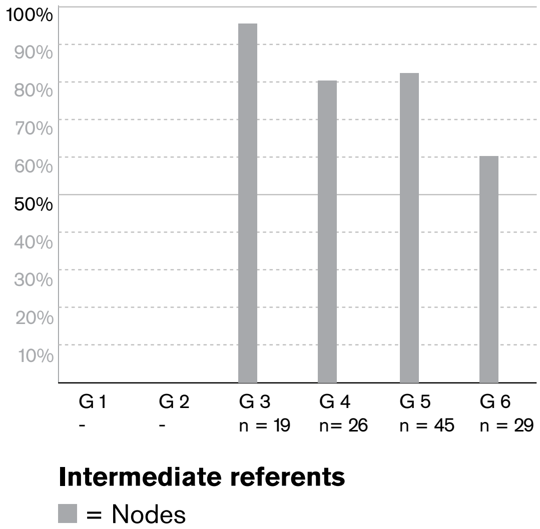
The coding variable includes one coding value which represents a general ineffective graphic tactic:

- Inconsistent text image relationship [5.3.2.1].

5.3.2.1 Pictorial object: inconsistent text image relationship

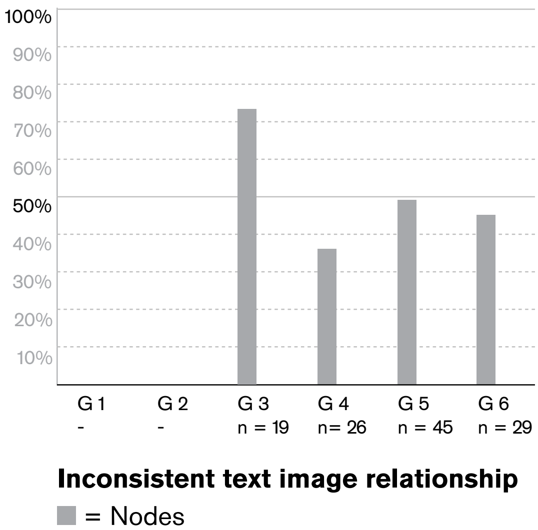
This section first presents the frequency of the 'neutral' coding values for intended and intermediate referents respectively, then the frequency of inconsistent text and image relationships. An average of 34% diagrams in the four diagram groups include one or more pictorial objects labelled with 'intended referents', *eg,* a picture of a fox labelled 'fox' [bar chart 5.11, next page]. Intermediate referents, *eg,* a picture of a fox labelled 'carnivore', are by far the most common labelling tactic appearing on average in 79% of the diagram groups [bar chart 5.12, next page].





Bar chart 5.11: Frequency of diagrams with instances of intended referents.
Bar chart 5.12: Frequency of diagrams with instances of intermediate referents.

The third coding value is a general ineffective graphic tactic. This coding value was identified by inconsistent text image relationships within the pictorial objects, *ie,* diagrams which include more than one of the three options: unlabelled pictorial objects, intended-, or intermediate referents.



Bar chart 5.13: Frequency of diagrams with inconsistent text image relationship

The incentive for including pictorial objects in a diagram may be both for decorative and cognitive effects. An intended referent may aide the cognition of the depicted concept according to Palvio's (1990) 'dual coding' theory. However, Chandler and Sweller (1991), when testing task-oriented diagrams, found that redundant labels increased the processing time, and instead recommend using complementary labels. Schriver (1997) recommends taking account of the audience level, skills, and interest. If choosing the intermediate referent tactic, the designer needs to consider the consistency of the included information types, *ie,* does each pictorial object represent a process or a broader description of organisms, *eg,* a rabbit labelled 'herbivore'. Crucially, the text image relationships may be consistent, yet polysemic. This ineffective graphic tactic arises from combinations of coding values.

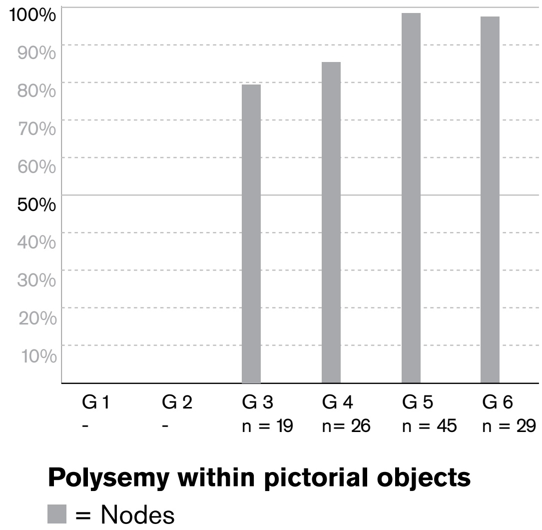
5.3.3 Ineffective graphic tactic arising from combinations of coding values within pictorial objects

Polysemy may arise from different combinations of coding values for pictorial objects within a diagram. These are here identified by drawing on coding values from coding variable 1 – nodes and connectors – and analysing combinations of coding values for unlabelled pictorial objects, 'multiple information types' and each of the six coding values for single information types - organisms, matter, material, pool, process, energy and forces – as found within pictorial object labels in a diagram. This results in one ineffective graphic tactic arising from the combination of coding values:

- Polysemy within pictorial objects [5.3.3.1]

5.3.3.1 Polysemy within pictorial objects

Polysemy within pictorial objects occurs at a very high frequency [bar chart 5.14, next page]. Only 10 diagrams in the data set include only one coding value within the pictorial objects. One of these is figure 4.27, [p. 127], which is 'multiple information types – monosemic; figure 4.32 [p. 134] demonstrates polysemy within pictorial objects.



Bar chart 5.14: Frequency of diagrams with polysemy within pictorial objects.

The combined findings of coding variable 2 suggest that graphic tactics for pictorial objects provides rich ground for improvements within existing practice.

5.4 Coding variable 3 – arrow types

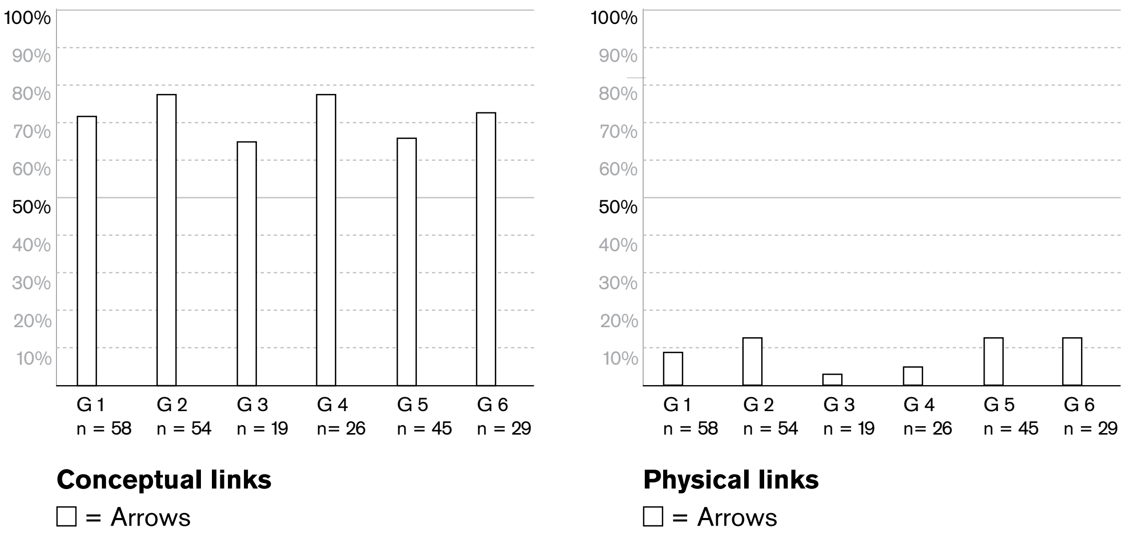
This coding variable was applied to identify the different arrow types included in the analysed diagrams [section 4.4.3, p. 136]. Graphic objects are identified by this coding value based on the information type included in the arrow label; thereby directly linked to identifying single information types in connector role through coding variable 1 [section 5.2, p. 165]. The information type represented by an arrow may result in two types of arrows – connectors and movement arrows – representing two categories of information: chemical transformations and transfers. Arrow types are thereby sub-categories within the connector role in relation to coding variable 1.

5.4.1 Information categorisation using arrow types

Coding variable 3 includes only 'neutral' coding values – conceptual link, physical link, movement between source and target, and movement of a source object. The ineffective graphic tactic which may arise from their combination is polysemy. Where coding variable 1 identified polysemy within the syntactic connector role, this coding variable identifies polysemy within the arrow types. This reveals whether chemical transfers and transformations are represented by visually similar arrows.

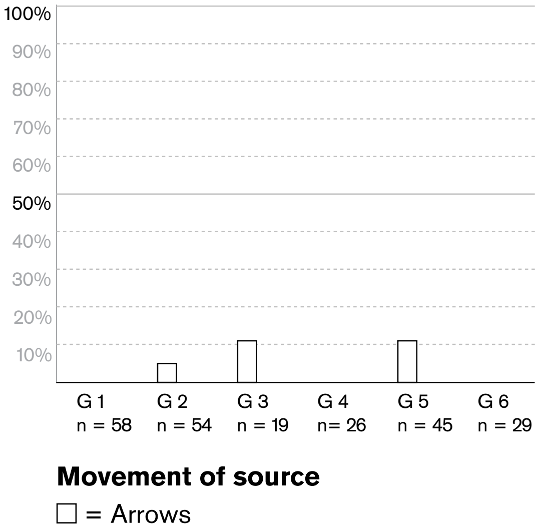
5.4.2 Ineffective graphic tactic arising from combinations of coding values within arrows

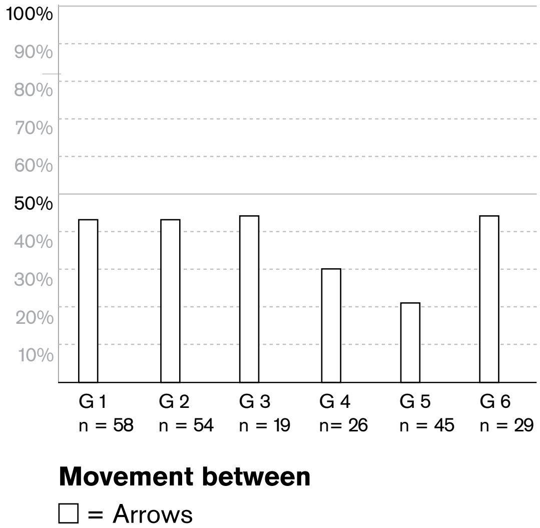
The frequencies of the 'neutral' coding values for arrow types are here presented. This reveals the general preferences for this graphic syntax aspect within the data set and the frequencies from which the identification of polysemic arrow types draws. The high frequency of conceptual links [bar chart 5.15, next page] here relates directly to the frequency of the coding value for the process information type – a potential ineffective graphic tactic described in section 5.2.3.3 [p. 172]. The physical link coding value [bar chart 5.16] was mainly identified in water cycles, *eg*, 'rivers' or as 'plant roots' in diagrams of the two other cycles.



Bar chart 5.15: Frequency of diagrams with instances of conceptual links.
Bar chart 5.16: Frequency of diagrams with instances of physical links.

The frequency of the 'movement between' coding value [bar chart 5.18] relates to coding values for single information types in coding variable 1, namely organism, material, and matter [section 5.2.3, p. 169]. The difference between the two sets of frequencies illustrates the difference between the two coding variables in this research enquiry. In coding variable 1, a diagram which includes an organism in one arrow label and matter in another, is identified by the two coding values for the related single information types. The same diagram is represented by only one arrow type coding value here in coding variable 3 – the 'movement between' arrow type. A diagram may thereby include polysemic connectors, *ie,* the syntactic role, but monosemic arrow types. The interrelation between single information types in connector roles and arrow types illustrates the precision with which both graphic syntax aspects need to be observed by the designer.





Bar chart 5.17: Frequency of diagrams with instances of 'movement of source' arrows.
Bar chart 5.18: Frequency of diagrams with instances of 'movement between' arrows.

The identified frequency of the 'movement between' coding value [bar chart 5.18] derives mainly from diagrams with organisms, *ie,* 'bacteria' rather than matter as the circulating element; hence indicating transfers of the wrong content proper element. This ineffective graphic tactic was discussed in section 5.2.3.1 [p. 170]. There is a low frequency of the 'movement of source' arrow type, as identified by the defined coding value [section 4.4.3.1, p. 138]. However, as was shown in figure 5.2 [p. 176], unlabelled arrows may also potentially be read as 'movement of source' if combined with labelled arrows. In such cases the element represented by the source node appears to be moving towards the element in the target node.

Arrow labels which include multiple information types [section 5.2.2.3, p. 168] are not identified as part of the arrow type coding variable because the multiple information types may relate both to movement and connectors. For example, a label which includes 'plant absorbs nutrients through roots' represents a conceptual link – an absorption process – a physical link – the roots – and movement of nutrients. This highlights, firstly, how the multiple information type coding value affects the effectiveness of the graphic tactics for arrow types; secondly again this highlights the intricate relationship between graphic syntax aspects, and how a decision for one aspect may affect the categorisation created by, and the interpretation of other aspects.

When identifying the ineffective graphic tactic arising from combinations of coding values, the two coding values for 'multiple information types' within connectors are considered. Although the exact arrow type is unclear in instances of these coding values, the arrows still represent chemical transfers and/or transformations. This coding value may thereby contribute to any potential ambiguity caused by polysemic arrow types.

5.4.2.1 Polysemic arrow types

The majority of diagrams in the data set includes 2-4 arrow coding values in the arrows [frequencies presented in appendix 6]. Several of these diagrams apply visual or typographic attributes to create visual distinction between arrows: however, none is precise in the distinction of different arrow types. Figure 5.4 [next page] illustrates the ambiguity caused by including polysemic arrow types.

Figure 5.4 includes an unlabelled arrow [a], 'movement between' [b], 'multiple information types - monosemic' [c], and conceptual link [d], all represented by visually similar arrows.

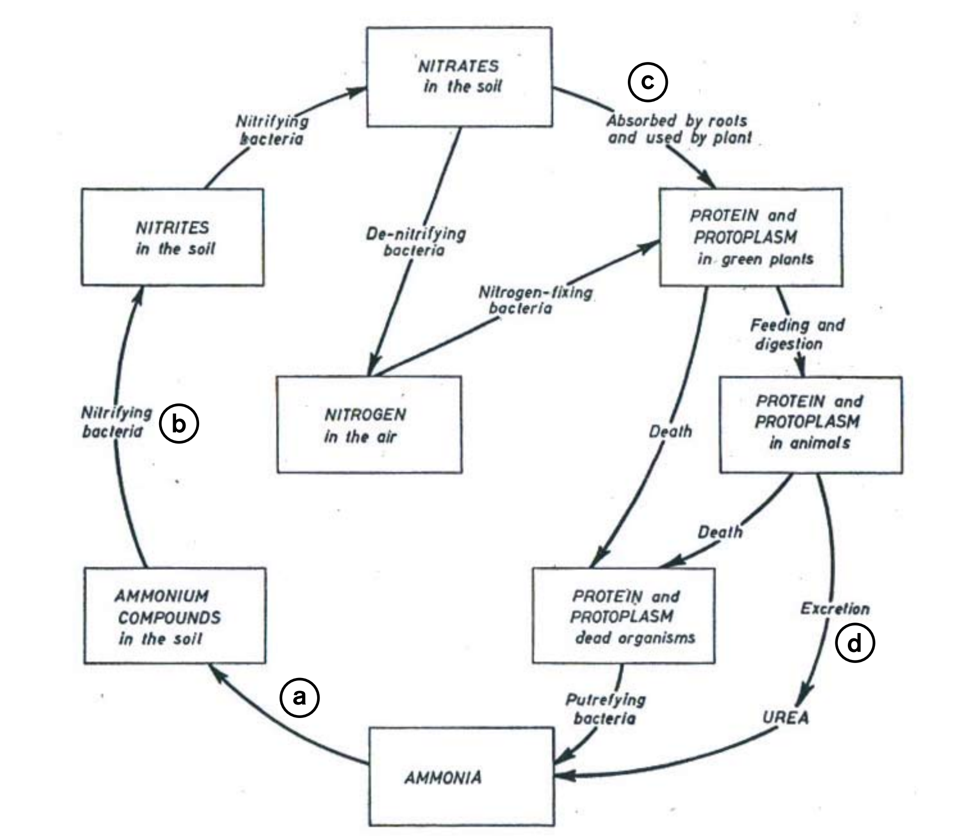


Figure 5.4: Diagram no 168

Graphic syntax aspect highlighted
Polysemic arrows:
Unlabelled arrow [a], 'movement between' [b], 'multiple information types - monosemic' [c], and conceptual link [d]

The nitrogen cycle
From: Brocklehurst (1962: 54)

This diagram thereby includes transformation of 'protein and protoplasm in animals' [d] and transfer of 'nitrifying bacteria' [b]. To this is added the unlabelled arrow [a]. Due to the inherent arrow meaning of movement and motion [section 4.4.1, p. 115], this may indicate that 'ammonia' moves towards 'ammonium compounds in the soil'. Finally, the multiple information types included in [c] represent a process inside an organism, *ie,* potentially a conceptual link. However, this arrow is, simultaneously, a physical link indicated by the roots. Finally, the arrow indicates 'movement of source object' by representing the absorption of the elements in the source node –

'nitrates in the soil'. Figure 5.4 thereby demonstrates how polysemic arrow types result in a diagram with mixed messages about the interrelations between the included content proper elements. Some connected elements are transformed, some are transferred, some are both. Arrow [c] also highlights an intricate relationship between verbal and graphic syntax which is discussed in section 5.6 [p. 198].

Figure 5.5, meanwhile, demonstrates the complicated interrelation between a polysemic syntactic role – the connectors – and polysemic arrows.

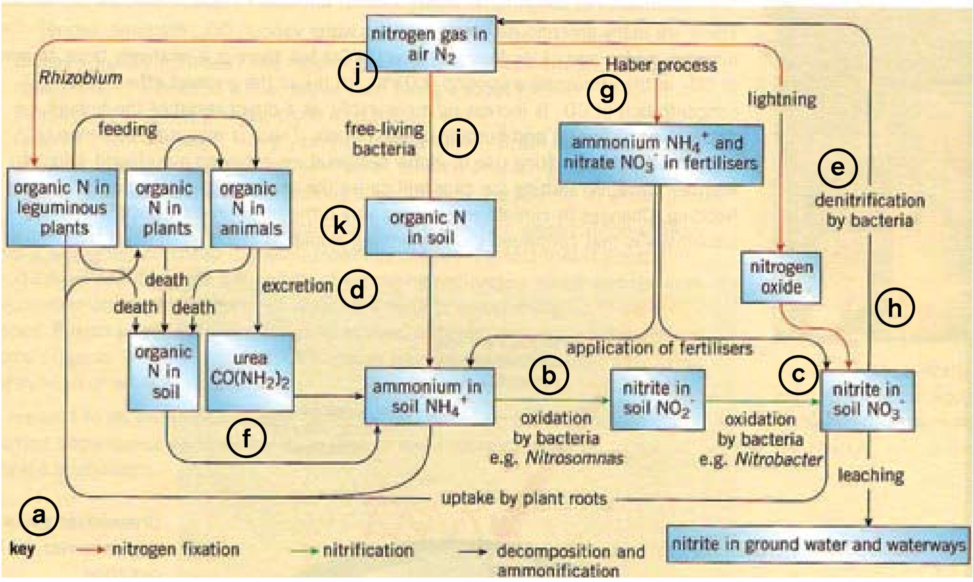


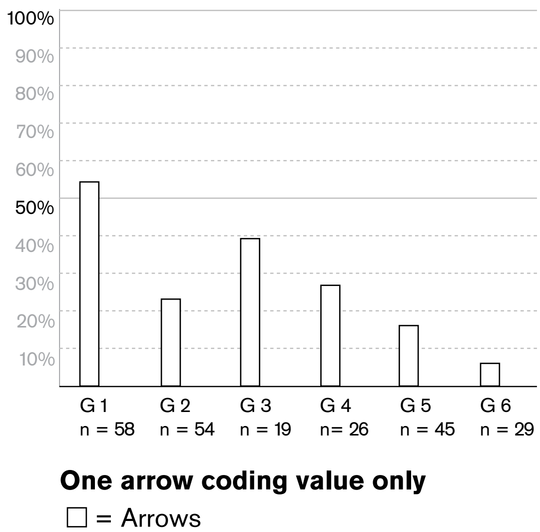
Figure 5.5: Diagram no 100

Graphic syntax aspect highlighted
Polysemic arrow types

The nitrogen cycle
Graham and Lewis (2001: 141)

The key [a] explains that red arrows represent 'nitrogen fixation', green arrows represent 'nitrification', and black arrows indicate 'decomposition and ammonification'. By representing processes, the three arrow types are conceptual links, *ie,* chemical transformations and the colour coding create sub-categories of processes. The green arrows [b and c] here exemplify consistent labelling, both indicating the process and process agent. However, the consistency of this categorisation is broken by the way information types are included in the labelling of the black arrows. Within the black arrows some labels indicate the specific process, *eg,* 'excretion' [d], some are further augmented with the process agent, *eg,* ‘denitrification by bacteria’ [e], and several are left unlabelled [*eg,* f], *ie,* the meaning specified only by the colour coding. This leaves the reader to wonder what types of decomposition or ammonification are represented by unlabelled arrows. Within the red arrows are found a process name ‘Haber process’ [g], an unlabelled arrow [h] and – more concerning – two arrows labelled with the process agents only, *eg,* ‘free-living bacteria’ [i]. Such instance of an organism coding value breaking the established pattern of ‘*process* by *organism*’ results in the arrow appearing as a movement arrow. As such the colour coding represents a transformation process, whilst the label potentially suggests that bacteria move from ‘Nitrogen gas in the air N_2’ [j] to ‘Organic N in the soil’ [k].

This example illustrates how a decision within one graphic syntax aspect – the inclusion of an organism in a connector – has effects for the categories of information created within another graphic syntax aspect – the arrow type. This example also demonstrates the need for considering all involved graphic syntax aspects when applying visual attributes. Coding variable 4 and 5 are applied to identify the consistency within each of these graphic syntax aspects respectively [sections 5.5, p. 191 and 5.6, p. 198]. One way to reduce polysemy among arrow types in a diagram is to include one coding value only. Unfortunately, the frequency of diagrams, which follow this tactic [bar chart 5.19] derive mainly from diagrams which are entirely unlabelled [bar chart 5.10, p. 175].



Bar chart 5.19: Frequency of diagrams with one arrow type only.

Unlabelled arrows have several implications for the logic of the linking sequence and interrelations between connected elements. This was demonstrated in section 5.2.4.1 above. Conceptual links are the second most frequent coding value within the quantities and may similarly represent an ineffective graphic tactic [section 5.2.3.3, p. 172] as may the exclusive inclusion of 'multiple information types – polysemic' [section 5.2.2.3, p. 168], or organisms [section 5.2.3.1, p. 170].

5.5 Coding variable 4 – visual attributes

Coding variable 4 is included in the coding scheme to analyse visual attributes as separate aspects [section 4.4.4, p. 139]. The coding values facilitate identification of nominal, ordinal, and quantitative sub-categories of information within and between nodes and connectors, for example, colour coding used to disassociate different processes within connectors.

5.5.1 Information categorisation using visual attributes

Visual attributes – shape, colour, texture, and size – applied to graphic objects in nodes and connectors were considered when identifying instances of the 'multiple information types' coding values [section 5.2.2.3, p. 168], and polysemy within nodes and connectors [section 5.2.3.4, p. 174] in coding variable 1, and polysemic arrow types in coding variable 3 [section 5.4.2.1, p. 186]. The analysis of the visual attributes as a separate graphic syntax aspect relates to creating positive redundancy when categorising information using the same visual attribute. Thereby the coding values and general ineffective graphic tactics relate to the inconsistency indicator of graphic ineffectiveness.

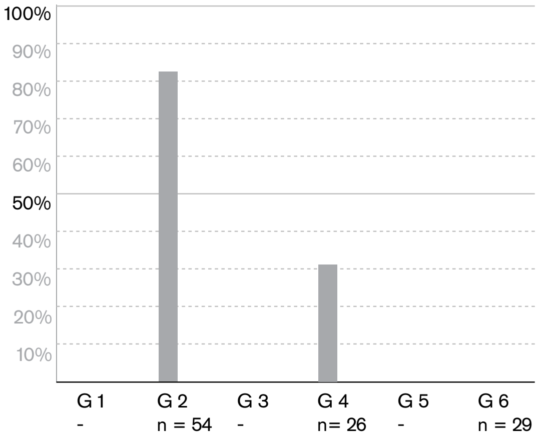
5.5.2 General ineffective graphic tactics within visual attributes

The coding variable includes four coding values which represent general ineffective graphic tactics:

- Nominal visual attributes: inconsistent shape [section 5.5.2.1, p. 191]
- Nominal visual attributes: inconsistent colour [section 5.5.2.2, p. 194]
- Ordinal visual attributes: inconsistent texture [section 5.5.2.3, p. 194]
- Quantitative visual attributes: inconsistent size [section 5.5.2.4, p. 195]

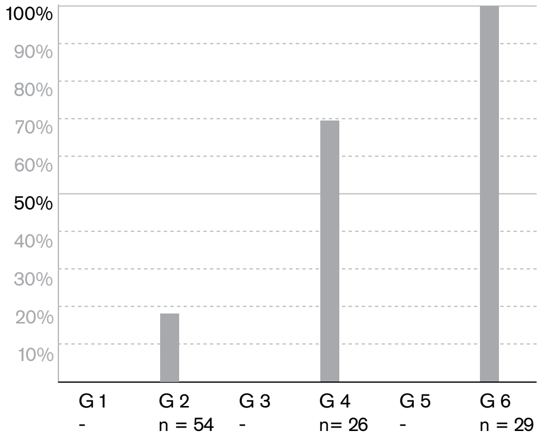
5.5.2.1 Nominal visual attributes – shape

The 'inconsistent shape' coding value was applied to identify categories of information within container shapes and arrows. Based on the grouping of diagrams in the data set, container shapes are found only in diagrams within G2, G4, and G6 (n=54, 26, 29) [section 4.2.1.1, p. 102], and only in nodal syntactic roles. Two general tactics for containing nodes are found within the data set: containing all nodes [bar chart 5.20] or containing only a sub-group of nodes [bar chart 5.21].



All nodes contained

■ = Nodes

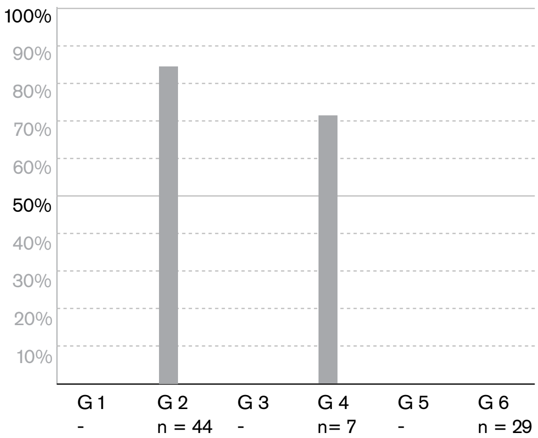


Some nodes contained

■ = Nodes

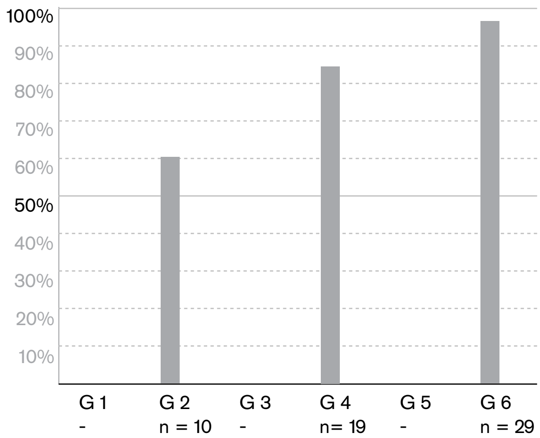
Bar chart 5.20: Frequency of diagrams with all nodes contained.
Bar chart 5.21: Frequency of diagrams with some nodes contained.

Inconsistent containment arises if visual association creates groups of disassociated elements (or sub-elements), or the opposite case, when associated elements are visually distinct. Containers which appear sized according to the amount of contained text are identified as visually similar as part of this frequency and are discussed in section 5.5.2.4 in relation to size. This ineffective graphic tactic is worryingly frequent within the data; both within diagrams with all nodes contained and only some nodes contained [bar chart 5.22 and 5.23].



All nodes contained – inconsistent

■ = Nodes



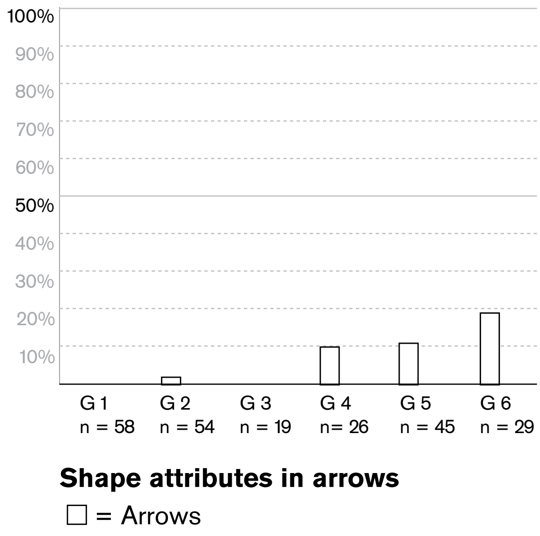
Some nodes contained – inconsistent

■ = Nodes

Bar chart 5.22: Frequency of diagrams with all nodes contained – inconsistently
Bar chart 5.23: Frequency of diagrams with some nodes contained – inconsistently

Only 10 diagrams within the data set apply consistent containment of all nodes; seven diagrams consistently contain some nodes. Consistent containment of only some nodes often represent a visual emphasis of the nodes which represent matter, particularly 'atmospheric nitrogen' in nitrogen cycles. Container shapes within G6 are often used to superimpose text objects onto the illustration background. The high frequency of inconsistency within G6 suggests less awareness of a container shape's effects – *ie,* creating nominal categories – when combining the four variables of full illustration, arrows, text objects, and container shapes. The shape of containers is discussed again in section 5.5.2.4 in relation to the size visual attribute. No diagram in G2, G4, G6 applies typographic styling to further distinguish between contained nodes, although, some apply colour coding [section 5.5.2.2, p. 194].

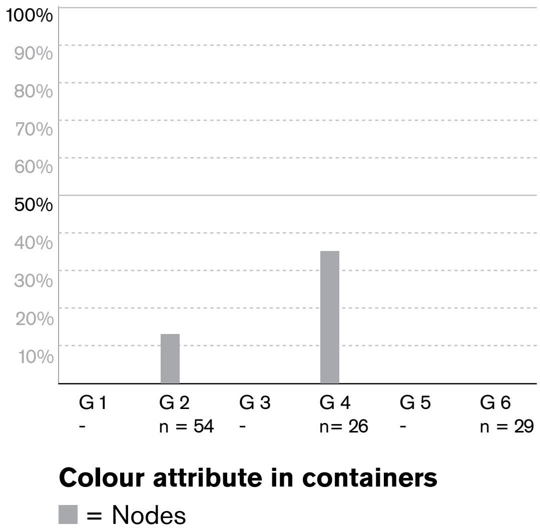
In terms of visual attributes applied to arrows, most diagrams within the data set apply just one shape, colour and texture to the included arrows. The frequencies reported in bar chart 5.24 reveal the number of diagrams in which the shape of *some* arrows is altered; mainly in older, black and white examples. Only three examples within these quantities are consistent in application of the shape attribute. These all apply a different shape to one arrow only, usually an arrow pointing from a 'photosynthesis' node, *ie,* indicating the production of oxygen. Most newer examples apply colour coding instead of shape attributes.

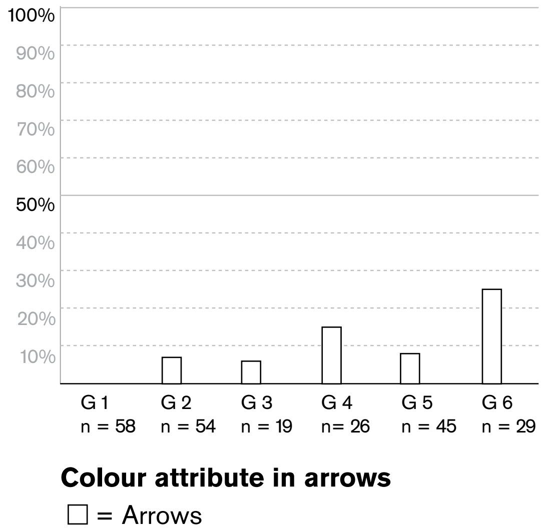


Bar chart 5.24: Frequency of diagrams with shape attributes in arrows. Only 3 diagrams within these quantities are consistent.

5.5.2.2 Nominal visual attributes – colour

Colour appears within container shapes only in G2 and G4. The colour attribute is mainly applied as spot colours or duo tones in examples dating from the late 1960 and 1970 and becomes more frequent in examples dated post 1980s. Colour is applied consistently within contained nodes [bar chart 5.26]– in all but one case – and arrows [bar chart 5.25]. Only one diagram applies the same colour coding to arrows and container shapes, this unfortunately demonstrating a general ineffective graphic tactic. [Figure 4.28, p. 128].

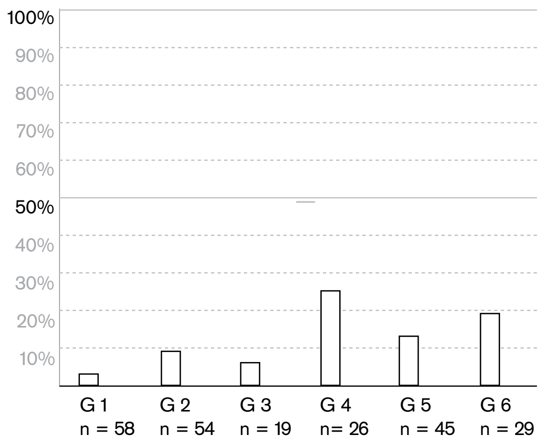




Bar chart 5.25: Frequency of diagrams with colour attribute in containers.
1 example within these quantities is inconsistent.
Bar chart 5.26: Frequency of diagrams with colour attribute in arrows.

5.5.2.3 Ordinal visual attributes – texture

The texture attribute appears most often in older diagrams, pre-colour printing. Bar chart 5.27 [next page] summarises the diagrams which include texture attributes in arrows. The attribute is not applied to contained nodes within the data set. Only two diagrams apply texture attributes consistently. This coding value relates directly to polysemic connectors and arrow types [sections 5.2.3.4, p. 174 and 5.4.2.1, p. 186]. In relation to ecological cycle network diagrams, the ordinal, *ie,* hierarchal nature of texture attributes creates an inherent conflict as was demonstrated in section 4.4.4.2 [p. 143]. It is therefore encouraging to find the colour attribute more frequent and consistent in contemporary diagrams.

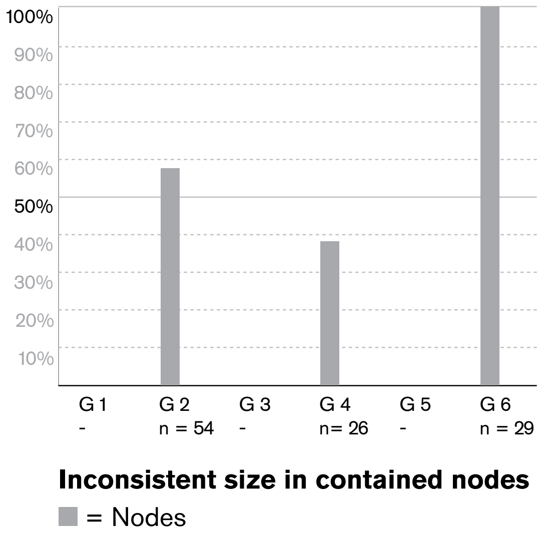


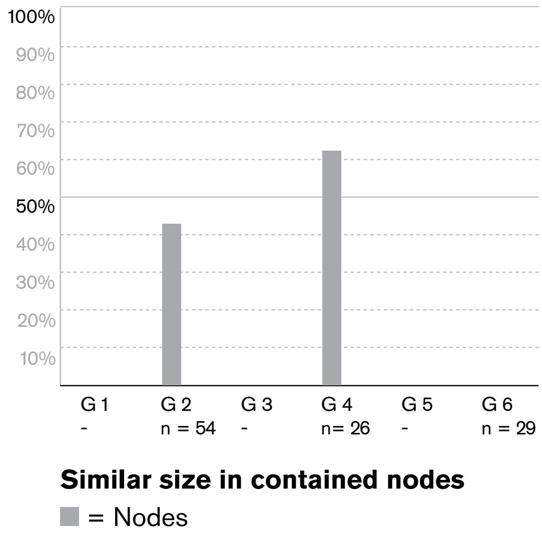
Texture attribute in arrows
☐ = Arrows

Bar chart 5.27: Frequency of diagrams with texture attribute in arrows. Only 2 examples within these quantities are consistent.

5.5.2.4 Quantitative visual attributes – size

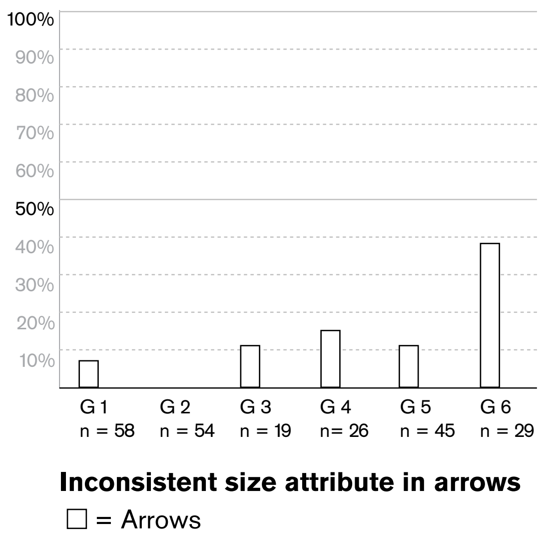
The size visual attribute creates quantitative hierarchies of included information [section 4.4.4.3, p. 145]. However, no diagram within the data set appears to apply size to container shapes to intentionally indicate quantitative categories. Instead the sizes of containers appear determined by the amount of text contained. Such application of the size attribute is inconsistent [bar chart 5.28], as exemplified by figure 5.5 [p. 188]. Here the different sizes of containers indicate different quantities of the contained elements. This general ineffective graphic tactic was previously highlighted by Garland (1968). Figure 5.4 [p. 187], meanwhile, reveals an inherent conflict when applying container shapes to a diagram. In figure 5.4 the identical size of the containers suggest equal quantities of the contained elements. However, the nodes are polysemic, combining the two coding values matter – ammonia – and 'multiple information types – monosemic'. Bar chart 5.30 [next page] presents the frequency of this general ineffective graphic tactic.





Bar chart 5.28: Frequency of diagrams with inconsistent size attribute in containers.
Bar chart 5.29: Frequency of diagrams with similar size attribute in containers.

No diagram within the data set applies size to arrows consistently. Only the coding value for inconsistent size was identified in arrows within the data set. The differences in size here appear determined by the space available, or the size attribute is applied to unlabelled arrows rendering the quantities implicit [figure 4.45, p. 146]. No diagram within the data set includes a legend for the represented quantities.



Bar chart 5.30: Frequency of diagrams with inconsistent size attribute in arrows.

Coding variable 4 was applied to analyse shape, colour, texture, and size visual attributes as a separate graphic syntax aspect. The findings from this analysis suggest that there is room for raising awareness in existing practice about the role of visual attributes. The need for precision with this graphic syntax aspect is underscored by the nature of visual attributes, *ie*, they create categories of information whether applied intentionally or unintentionally.

Diagrams within the data set which are not represented in the above discussed quantities apply one shape, colour, and size attribute to the arrows. The effectiveness of this graphic tactic depends on the number of information types categorised within the connectors, thereby, relating to coding variable 1 and polysemic connectors [section 5.2.3.4, p. 174].

5.6 Coding variable 5 – typographic attributes

This coding variable was used to identify visual attributes applied to text objects in network diagrams. These are analysed as typographic attributes to provide added detail on sub-categories of information created by this graphic syntax aspect [section 4.4.5, p. 147]. The analysis of typographic attributes is informed by Richards (1984) and complements the graphic syntax aspects outlined by Engelhardt (2002).

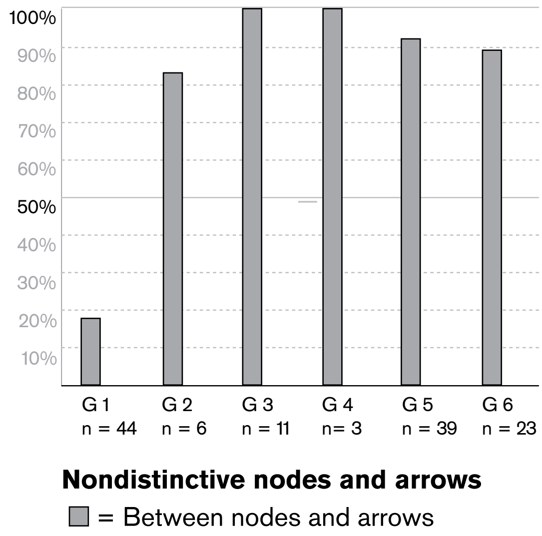
5.6.1 Information categorisation using typographic attributes

This coding variable is used solely to identify typographic attributes applied to visually disassociate nodes from connectors in the individual diagrams. Typographic attributes applied to create sub-categories within nodes or connectors were considered as part of identifying polysemy within the syntactic roles [section 5.2.3.4, p. 174. The single coding value for typographic attributes relate to the inconsistency indicator of ineffective graphic tactics and represents a general ineffective graphic tactic:

- Nondistinctive nodes and arrow labels

5.6.1.1 Typographic attributes – nondistinctive nodes and arrow labels

Nondistinctive nodes and arrow labels represent ineffective graphic tactics when the same typographic attribute is applied to any single, non-contained nodal text object, and any arrow label within the same diagram. This analytical focus results in excluding several diagrams from this analysis with this coding variable: diagrams which include only unlabelled arrows [section 5.2.2.2, p. 167] and/or diagrams in which all the nodes are contained [section 5.5.2.1, p. 191]. This results in different totals within the diagram groups for this coding variable as indicated in bar chart 5.31 [next page].



Bar chart 5.31: Frequency of diagrams with nondistinctive nodes and arrows.
Please note different totals from overall diagram groups.

Diagrams applying no typographic distinction between instances of connected and connecting text objects demand increased scrutiny from the reader to distinguish nodes from arrow labels, *ie,* connected elements from the ones connecting. When typographic distinction is applied in diagrams within the data set, nodes and arrow labels are most commonly disassociated by upper case in nodes, and lower case in labels. This graphic tactic emphasises the connected content proper elements and mirrors the emphasis on nodes created by containment. Typographic emphasis on nodes also unravels an inherent conflict within both of these graphic syntax aspects. Bertin (1983: 36) states that the graphic representation of nominal information categories needs to reflect their – nominal – equal importance. Thus he advises against visual emphasis of one group. Bertin's advice thereby highlights the designer's challenge when aiming at making an informed decision about distinguishing elements through typographic or visual attributes.

5.7 Coding variable 6 – verbal syntax

The verbal syntax of text objects may create association or disassociation between the graphic objects and thereby groupings of the related content proper elements. This coding variable was used to analyse whether the verbal syntax of text included within nodes or arrow labels are consistent or inconsistent in such association [section 4.4.6, p. 150].

5.7.1 Information categorisation using verbal syntax

The analysis of verbal syntax in network diagrams was developed during the pilot content analysis. This analysis was prompted by the variation found within nodes and arrow labels when identifying the 'multiple information types' coding values [section 5.2.2.3, p. 168]. This revealed several interrelations between the structure of verbal syntax in text objects and the graphic syntax linking. It is beyond the scope of this research enquiry to identify each individual combination of verbal syntax. Instead, the coding variable includes two coding values for identifying inconsistent verbal syntax in nodes and arrows respectively. These coding values each represent general ineffective graphic tactics related to the inconsistency indicator of graphic ineffectiveness [section 5.7.2, p. 201]. The third coding value for identifying nouns in arrow labels relates directly to the coding values for arrow types and single information types in the connectors. An ineffective graphic tactic here arises if the reader identifies the arrow as a 'movement between' arrow type [section 5.7.3, p. 201].

In addition to presenting the frequencies of coding values, some key issues found within the potential wide range of verbal syntax tactics deserve elucidation in this thesis. These issues are presented in appendix 7 and reveal four general ineffective graphic tactics:

- Inconsistent linear linked verbal syntax
- Inconsistent noun and verb phrases
- Inconsistent passive and active voice
- Inconsistent prepositions

These theoretical contributions may serve as corner stones in future detailed mapping of this interesting junction between graphic and verbal syntax.

Staying within the scope of the coding scheme, the following sub-section reports on frequencies of the verbal syntax coding values, *ie,* general ineffective graphic tactics.

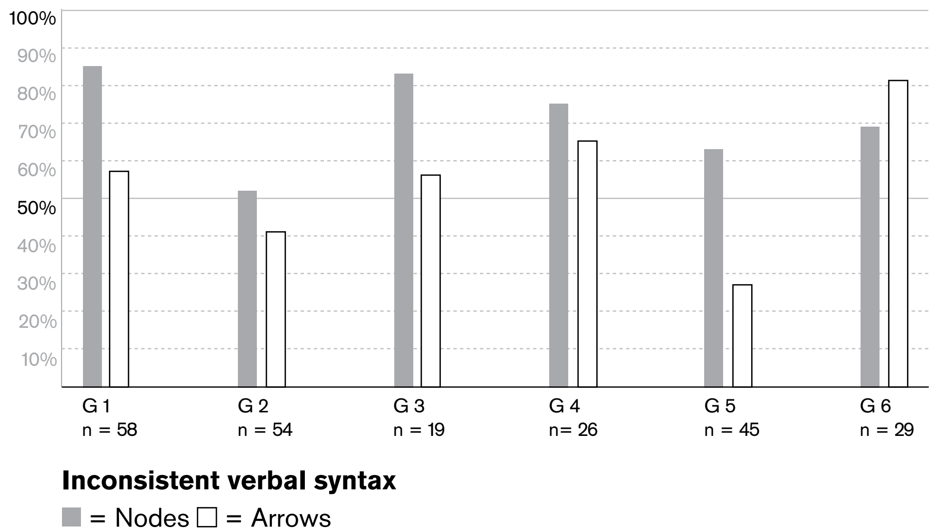
5.7.2 General ineffective graphic tactics within verbal syntax

This coding variable includes two coding values which represent general ineffective graphic tactics:

- Inconsistent verbal syntax in nodes [section 5.7.2.1, below]
- Inconsistent verbal syntax in arrows [section 5.7.2.1, below]

5.7.2.1 Frequencies of inconsistent verbal syntax in nodes and arrows

Both general ineffective graphic tactics appear at a worrying high frequency within the data set [bar chart 5.32]. On average, 71% of the diagrams in the analysis groups include inconsistent verbal syntax within the nodes. Although arrow labels fare slightly better, an average of 55% of the analysed diagrams have inconsistent verbal syntax within the arrow labels.



Bar chart 5.32: Frequency of diagrams with inconsistent verbal syntax.

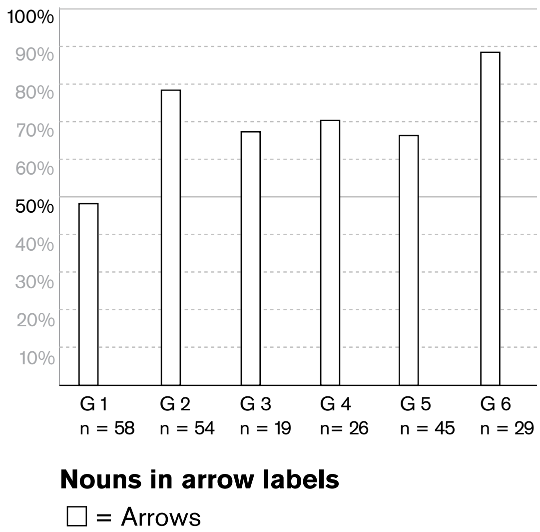
5.7.3 General ineffective graphic tactics within verbal syntax

One ineffective graphic tactic may arise from the combination of coding values in relation to verbal syntax:

- Noun arrow labels [section 5.7.3.1]

5.7.3.1 Nouns in arrow labels

It is also worrying, that an average of 60% of diagrams in the analysis groups include noun arrow labels [bar chart 5.32] – which may potentially be read as movement arrows [section 5.4.2, p. 183].



Bar chart 5.33: Frequency of diagrams with noun arrow labels.

This frequency is worrying, firstly, because it relates directly to the frequency of the organism coding value [section 5.2.3.1, p. 170] and in turn the limited number of diagrams which include matter in connector roles [section 5.2.3.2, p. 171], *ie,* organisms appearing to be circulating. A second concern is that a high proportion of this frequency derives from arrow labels which include the process information type. When a process is represented with a noun, the verbal syntax may affect the initial reading of the arrow type as a movement arrow rather than a conceptual link. Further this affects the diagram's message about the circulating, the connected, and the connecting elements. Not only are some processes dislocated outside their related organisms, they may also appear to be circulating.

This sub-section concludes the presentation of the frequencies of coding values and the ineffective graphic tactics which may arise from their combination. The next section presents an overview of the ineffective graphic tactics, and the observed effects on the content proper message.

5.8 Overview of ineffective graphic tactics

The visual content analysis revealed 29 ineffective graphic tactics in existing visual output, as represented by the UK data set in this enquiry. This section presents an overview of these ineffective graphic tactics, set out in tabular format. The interrelations between coding values are then illustrated using an individual ecological cycle network diagram. Finally, the table is used to detect the extent of the ineffective graphic tactics in the sample of four Danish diagrams. This demonstrates how the table may be used by current practitioners as an evaluation tool for ecological cycle network diagrams.

5.8.1 List of 29 ineffective graphic tactics

Table 5.1 summarises the 29 ineffective graphic tactics identified through this research enquiry – 17 general and 12 arising from combinations of coding values – The table is ordered according to the coding variables, *ie,* each graphic syntax aspect. The listing of each ineffective graphic tactic includes reference to the sections in which they are discussed, the potential effect of each tactic on the content proper message, and the interrelated coding values. This latter listing is part of unravelling the level of potential theoretical complication within the design problem space posed by an ecological cycle network diagram [section 5.4, p. 183].

Table 5.1 overview of ineffective graphic tactics found in data set			
Ineffective graphic tactic		**Potential effect on content proper**	**Related coding values**
Coding variable 1 – node and connector syntactic roles			
1	Implicit nodes: Branching arrow Section [4.4.1.1 / 5.2.2.1]	Indicates an implicit connected element. Ambiguity about nature of connected and connecting element.	Not applicable in this analysis – analysed separately from explicit nodes.
2	Implicit nodes: Merging arrows Section [4.4.1.2 / 5.2.2.1]		
3	Implicit nodes: Arrow-arrow connection Section [4.4.1.3 / 5.2.2.1]		
4	Implicit nodes: Intersecting arrows Section [4.4.1.4 / 5.2.2.1]		

Table 5.1 overview of ineffective graphic tactics found in data set

Ineffective graphic tactic		Potential effect on content proper	Related coding values
5	Imprecise nodes/arrow labels: Imprecise relative spatial positioning [Section 4.4.1.5 / 5.2.2.1]	Ambiguity about the nature and role of connected and connecting element.	Coding variable 2: Pictorial object labels Coding variable 5: · Nondistinctive nodes and arrows
6	Explicit nodes: Unlabelled pictorial object [Section 4.4.1.6 / 5.2.2.2]	Polysemic connected object. Ambiguity about nature of connected element.	Coding variable 1: · Polysemy within nodes Coding variable 2: · Polysemic pictorial objects
7	Explicit connectors: Unlabelled arrow [Section 4.4.1.6 / 5.2.2.2]	Polysemic connected object. Ambiguity about nature of connecting element.	Coding variable 1: · Polysemy within connectors Coding variable 3: · Polysemic arrow types
8	Explicit nodes and connectors: Multiple information types – polysemic [Section 4.4.1.7 / 5.2.2.3]	Hinders positive redundancy when reading diagram. Ambiguity about the nature and roles of connected or connecting elements.	Coding variable 1: · Polysemy within nodes or connectors. Coding variable 2: · Polysemic pictorial objects Coding variable 3: · Polysemic arrow types Coding variable 6: · Verbal syntax
9	Categorising organisms in connector roles [Section 4.4.1.6 / 5.2.3.1]	Elements such as bacteria appear as circulating, rather than agents of transformation processes.	Coding variable 3: · Arrow types
10	Explicit connectors: Excluding matter from connector roles [Section 4.4.1.6 / 5.2.3.2]	Essential circulating elements are implicit; ambiguity about the nature of connecting elements.	
11	Explicit connectors: Process in connector roles [Section 4.4.1.6 / 5.2.3.3]	May dislocate processes outside their related element. Creates ambiguity about the role of connecting elements.	
12	Exclusively unlabelled arrows [Section 4.4.1.6 / 5.2.3.4]	Ambiguity about the nature and role of connected element. May indicate movement of elements in source nodes.	Coding variable 1: · Polysemy within nodes Coding variable 6: · Verbal syntax

Table 5.1 overview of ineffective graphic tactics found in data set			
Ineffective graphic tactic		**Potential effect on content proper**	**Related coding values**
13	Polysemy within a syntactic role [Section 4.3.1.7 / 5.2.3.4]	Ambiguity about the nature and role of connected or connecting elements. Hinders positive redundancy when reading a diagram.	Coding variable 1: · Single information types Coding variable 2: · Polysemic pictorial objects Coding variable 3: · Polysemic arrow types Coding variable 4: · Visual attributes Coding variable 5: · Typographic attributes
Coding variable 2 –pictorial object labels			
14	Text image relationship inconsistent [Section 4.4.2.1 / 5.3.2.1]	Ambiguity about the nature of connected elements. Hinders positive redundancy when reading a diagram.	Coding variable 1: · Single information types · Multiple information types
15	Polysemic pictorial objects [Section 4.4.2.1 / 5.3.3.1]	Ambiguity about the nature of connected elements.	Coding variable 1: · Single information types · Multiple information types · Polysemy within nodes Coding variable 4: · Visual attributes Coding variable 5: · Typographic attributes
Coding variable 3 – arrow types			
16	Polysemic arrow types [Section 4.4.3 / 5.4.2.1]	Ambiguity about the nature and role of connected or connecting elements. Hinders positive redundancy when reading a diagram.	Coding variable 1: · Single information types · Multiple information types · Polysemy within connectors Coding variable 4: · Visual attributes Coding variable 5: · Typographic attributes

Table 5.1 overview of ineffective graphic tactics found in data set

Ineffective graphic tactic		**Potential effect on content proper**	**Related coding values**
Coding variable 4 – visual attributes			
17	Nominal visual attributes: Inconsistent shape [Section 4.4.4.1 / 5.5.2.1]	Ambiguity about nature of grouped elements within nodes or arrows.	Coding variable 1: · Single information types · Multiple information types · Polysemy within nodes and connectors
18	Nominal visual attributes: Inconsistent colour within syntactic role [Section 4.4.4.1 / 5.5.2.2]		
19	Nominal visual attributes: Inconsistent colour *between* syntactic roles [Section 4.3.4.1 / 5.2.4.2]	Ambiguity about nature and role of grouped elements between nodes or arrows.	
20	Ordinal visual attributes: Inconsistent texture [Section 4.4.4.2 / 5.5.2.3]	Ambiguity about nature and hierarchy of grouped elements within nodes or arrows.	
21	Quantitative visual attributes: Inconsistent size [Section 4.4.4.3 / 5.5.2.4]	Ambiguity about relative quantities represented, the hierarchy, and nature of grouped elements within nodes or arrows.	
Coding variable 5 – typographic attributes			
22	Nondistinctive nodes and arrow labels [Section 4.4.5.1 / 5.6.1.1]	Ambiguity about role of connected or connecting elements.	Coding variable 1: · Single information types · Multiple information types
Coding variable 6 – Verbal syntax			
23	Inconsistent verbal syntax in nodes [Section 4.4.6.1 / 5.7.2.1]	Hinders positive redundancy when reading a diagram; ambiguity about nature and role of connected elements	Coding variable 1: · Single information types · Multiple information types
24	Inconsistent verbal syntax in arrow labels [Section 4.4.6.1 / 5.7.2.1]	Hinders positive redundancy when reading a diagram; ambiguity about nature and role of connecting elements	
25	Noun in arrow labels [Section 4.4.6.1 / 5.7.3.1]	May result in reading a 'movement between' arrow type and chemical transformation instead of transfer.	Coding variable 1: · Single information types · Multiple information types Coding variable 3: · Arrow types

Table 5.1 overview of ineffective graphic tactics found in data set			
Ineffective graphic tactic		**Potential effect on content proper**	**Related coding values**
Verbal and graphic syntax interactions [appendix 7]			
26	Inconsistent linear verbal link within graphic objects [Appendix 7]	Verbal syntax may emphasise or verbally direct the visual routing. Indicating start and finishing points in content proper.	Coding variable 1: · Single information types · Multiple information types Coding variable 3: · Arrow types Coding variable 5: · Typographic attributes
27	Inconsistent noun and verb phrases [Appendix 7]	Verbal syntax may emphasise or verbally direct the visual routing. A 'broken' verbal link hinders positive redundancy when interpreting the text objects and verbal omissions may increase ambiguity about nature and role of elements	
28	Inconsistent passive and active voice [Appendix 7]	Indicates which of linked text objects serve as grammatical objects and subjects. Active voice indicates the element in first node as the grammatical agent, passive voice indicates element in arrow as grammatical agent. May increase ambiguity about nature and role of elements	
29	Inconsistent prepositions [Appendix 7]	Indicates spatial and temporal relations between content proper information categories within single text object and in turn the connected / connecting elements. May increase ambiguity about nature and role of elements	

Table 5.1: Overview of ineffective graphic tactics found in the data set of 205 UK ecological cycle network diagrams.

5.8.1.1 General effects on the content proper message in ecological cycle network diagrams

The ineffective graphic tactics listed in table 5.1 were found by analysing how six information types were categorised using each of six graphic syntax aspects, in relation to four indicators of graphic ineffectiveness. Two general effects on the content proper message emerge from the list, both of which leads to a third. The first general effect to emerge is when the information categorisation potentially creates ambiguity about the nature of included content proper elements, for example, implicit nodal points or single instances of polysemy creating ambiguity about the nature of the possible 'hidden' element. The second general effect on the content proper message is confusion about the role of included elements, *ie,* as connecting or connected. This may similarly be caused by implicit or polysemic nodes or imprecise relative spatial positioning of graphic objects.

When the two general effects on the content proper message occur together, they create ambiguity about both the nature and the role of individual elements and their relation to other elements in the ecological cycle. The level of ambiguity within an individual diagram depends on the particular combination of information types and graphic syntax aspects. Critical combinations include an 'active' content proper element appearing in a 'passive' syntactic role – *eg,* matter generally appearing 'stored' in nodal elements – rather than circulating – or the opposite case, if bacteria is seen as a moving element. This results in illogical linking sequences: circulating elements are implicit, chemical transfer and transformations are confused, and several processes may be implicitly represented in the same graphic object. This brings general confusion about the type of element that circulates between the others, *ie,* that circulation of matter is the essential feature of an ecological cycle. The interrelation between the ineffective graphic tactics and how they may affect the content proper message may be demonstrated by analysing a single ecological cycle network diagram, using the list of ineffective graphic tactics [table 5.1].

5.8.1.2 Interrelations between ineffective graphic tactics

The interrelations between different coding values have been highlighted throughout sections 5.2-5.7, indicating how a decision within one graphic syntax aspect may affect the effectiveness of graphic tactics within other aspects. Figure 5.6 serves as a particularly interesting example for illustrating these interrelations. This diagram includes 23 of the 29 listed ineffective graphic tactics. These are identified in appendix 8, which demonstrates how table 5.1 may be used as a check list by practitioners to identify ineffective graphic tactics in ecological cycle network diagrams.

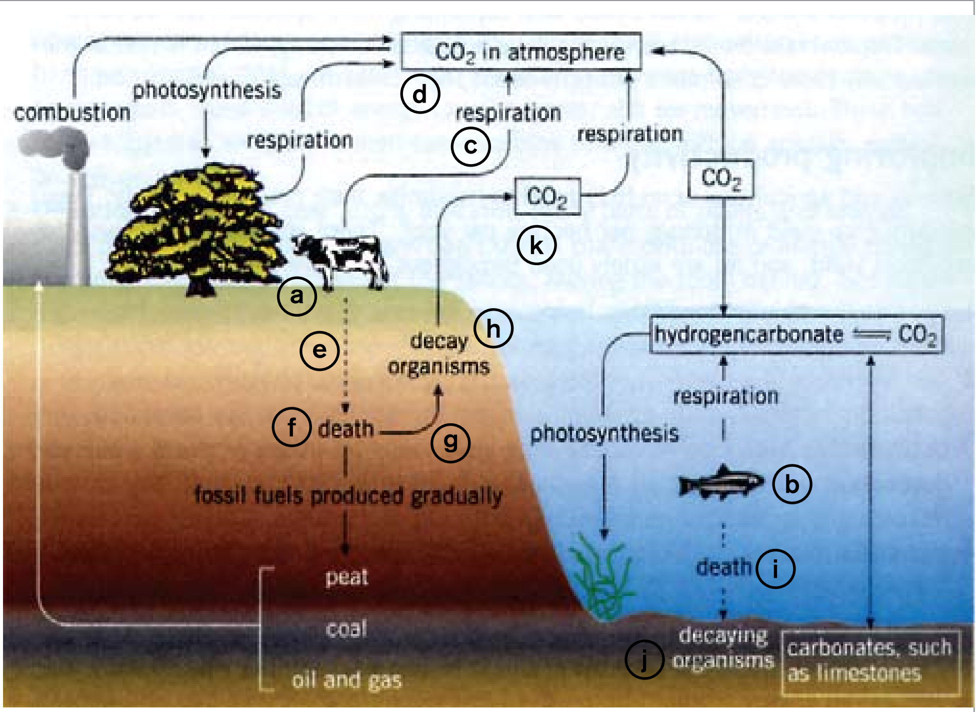


Figure 5.6 Diagram no 188

The carbon cycle
From: Graham and Lewis (2001: 140)

The three general effects on the content proper message – ambiguity about the nature, and role of elements, leading to illogical linking sequences – may be demonstrated by three node-connector sequences, starting by the pictorial object of a cow [a]. The pictorial object is unlabelled, consequently, the nature of the intended meaning is implicit. It is here assumed that [a] means 'cow', however, it could mean, *eg,* 'animals', 'herbivore', 'consumers', 'digestion', or 'feeding', although, sadly – for the cow – it appears to die and exhale only, given there is no incoming arrow to this node. The meaning represented by the pictorial fish node [b] suffers a similar destiny.

The linking of the node [a] shows the role of the cow within the carbon cycle. The node is conceptually linked by 'respiration' [c], to 'CO_2 in the atmosphere' [d]. This could indicate a transformation of the cow into matter. Meanwhile the unlabelled arrow [e] exiting the cow, *ie,* node [a], may be read as motion, *ie,* a transfer. The cow here appears to be physically moving towards 'death' [f] which is itself located underground. 'Death' [f] – process – is itself linked with an unlabelled arrow [g] to 'decay organisms' [h] – organisms. The process thereby appears to move towards 'decay organisms'.

The sequence involving the fish node [b] here differs, by 'death' [i] instead moving between the fish and 'decaying organisms' [j].

The 'decay organisms' [h] meanwhile – or subsequently? – move out of the soil and into the air towards 'CO_2' [k]. Whilst a lot of movement appears to take place, the circulation of matter remains implicit. If the unlabelled arrows are instead meant as transformations, then the sequence explains that death [f] becomes decay organisms [h] which turn into 'CO_2' [k]. The confusion about the essential circulating element is further extended by visually positioning a 'CO_2' node [k] in the middle of the atmosphere, the element moving towards 'CO_2 in the atmosphere' [d]. 'CO_2' here appears to move through the atmosphere before appearing 'in' it.

The information categorisation here identified – through node and connector syntactic roles, unlabelled pictorial objects and arrows, and inconsistent verbal syntax – creates confusion about, rather than answers, three basic questions: 'what type of elements are included?'; 'What does an element do in relation to the other elements?'; 'What is it that goes round in the cycle?'. Underlying this issue is the challenge of simultaneously representing chemical transfers and transformations within the same diagram, as well as the elements being transferred, the process agents, and elements within which the transformations take place. Accommodating such a range of information results in individual node-connector-node combinations representing different features of the respective ecological cycle. In turn this communicates a fundamental mixed and ambiguous message. The analysis of figure 5.6 thereby demonstrates how the analysis presented in this thesis reveals formal inadequacies that may increase the reader's effort in disambiguating the intended message. These inadequacies are present both within UK and Danish visual outputs. The latter was found by analysing a sample of four Danish ecological cycle network diagrams.

5.8.1.3 Ineffective graphic tactics in sample of Danish diagrams

The geographical scope of this research enquiry extends to Denmark and the current market for science textbooks for 14-18 year age groups. This is based, firstly, on the researcher's own design practice extending between these two countries, and a wish to potentially enhance design practice in both. Secondly, the research enquiry includes Danish visual output and professional practice to investigate how the different flexibility in the exam specifications for ecological cycles may affect the information transformation rationale [chapter 6]. Four ecological cycle network diagrams from publications currently on the Danish market were analysed using the coding scheme and table 5.1. This analysis is documented in appendix 9. The four Danish diagrams include, 8, 14 ,13, and 8 of the identified ineffective graphic tactics respectively.

The visual content analysis in this research enquiry thereby reveals similar information categorisation patterns within visual output from both countries, hence similar formal inadequacies in the visual output. This, in turn, suggests that designers in both countries take similar paths when navigating among the internal constraints (Lawson, 2006) of an ecological cycle network diagram – *ie,* the complex network of decision-making posed by the ill-defined design problem space [section 4.5.1, p. 155]. Paths which potentially result in the three general effects on the content proper message: ambiguity about the nature and the role of elements, and the essential circulating element.

The presented overview of the identified ineffective graphic tactics may now be positioned within the context of the design problem space. This sets the ground for identifying the information transformation rationale within the professional practice context [chapter 6] and later recommending alternative graphic strategies and tactics [chapter 7].

5.9 Ineffective graphic tactics in the design problem space

In chapter 4, the coding scheme for the visual content analysis was defined as the design problem space being investigated in this research enquiry [section 4.5, p. 155]. In this definition the coding variables represent sub-problems, each with a set of sub-solutions. Thereby the coding values, as graphic tactics, represent sub-problem-solution pairings (Dorst and Cross, 2001) [section 2.4.2.2, p. 44], and the ineffective graphic tactics represent ineffective sub-problem-solution pairings.

5.9.1 Ineffective sub-problem-solution pairings

The visual output from an educational publisher, *ie,* each analysed ecological cycle network diagram, represents an existing solution to the design problem defined by the coding scheme in this research enquiry [figure 4.51, p. 154]. Each ineffective graphic tactic represents an ineffective sub-problem-solution pairing within these overall solutions (Dorst and Cross, 2001) [section 2.4.2.2, p. 44]. Decisions for such sub-problem-solution pairings thereby affect the effectiveness of the overall solution. Firstly, an ineffective sub-problem-solution pairing may affect the content proper message; secondly, the ineffective pairing affects the choices within related sub-problems. The interrelations to other sub-problems, *ie,* coding variables, may be both complementary and conflicting (Rowe, 1987; Dorst and Cross, 2001).

Some conflicting interrelations are due to the nature of graphic syntax. For example, the use of bold letters to distinguish nodes from arrow labels conflicts with Bertin's (1983) recommendations for applying non-hierarchal visual attributes on information categories which are of equal importance [section 5.6.1.1, p. 198]. Other conflicting relations are due to the nature of the ecological cycle subject, and information types included in the diagrams. For example, if opting for exclusive, *ie,* consistent, use of conceptual linking, the designer faces the conflict of dislocating processes such as 'photosynthesis' [section 5.2.3.3, p. 172], and potentially representing the processes as moving between other elements [section 5.4.2.1, p. 186]. The internal constraints of this particular design problem space thereby prove challenging when wishing to categorise up to six information types in a network diagram whilst aiming at reducing implicit nodes, imprecise nodes, polysemy, and inconsistency. This in turn complicates the design of a ecological cycle network diagram as a 'well-operating machine' (Doblin, 1980: 104), *ie,* a clear and effective diagram [section 2.2 p. 30].

Buchanan (2001) embraces the notion of a graphic language, studying visual communication design products as visual arguments. He uses the rhetorical concepts of logos, pathos and ethos (2001: 195-197). In an information design context, logos relates to the intelligent and rational structure of a diagram[2]. A successful logos, according to Buchanan (2001: 195), is a product 'capable of doing its work'. This reflects Doblin's 'well-operating machine' analogy (1980: 104). Seen in this context, the ineffective graphic tactics found in existing visual output [table 5.1, p. 203] reveal a future challenge for design practice in educational publishing: the task of improving the logos of the ecological cycle network diagrams. In this thesis, the logos is seen as the articulation of the nature of included content proper elements, their individual role in the cycle, and the logic in their sequential linking through the six graphic syntax aspects. This focus points both to the defining and planning of source information – *ie,* deciding which features of the cycle to include in any one diagram – and to the effective composition of graphic objects in relation to precision in communication. The task of improving the logos thereby points to the essential information design activities [section 2.1.2, p. 26]. The next chapter identifies the features within the professional practice, which may affect how the source content and composition of biological content using graphic objects is decided, as well as the reasoning guiding these design decisions.

2 Buchanan suggests pathos as, *eg,* product's physical, cognitive, emotional or cultural suitability to the specific user. Ethos is the product's 'voice', *eg,* the visual aesthetic style as well as the logos and pathos combined.

Summary

This chapter has presented the findings from the visual content analysis as part of the *first research strand*.

The visual content analysis found 29 ineffective graphic tactics in the data set of 205 UK ecological cycle network diagrams. 17 of these are general ineffective graphic tactics represented as coding values in the coding scheme. An additional eleven ineffective graphic tactics may arise from combinations of coding values – related to syntactic roles, pictorial objects, arrow types, and verbal syntax. The effects on the content proper message were demonstrated using examples from the UK data set.

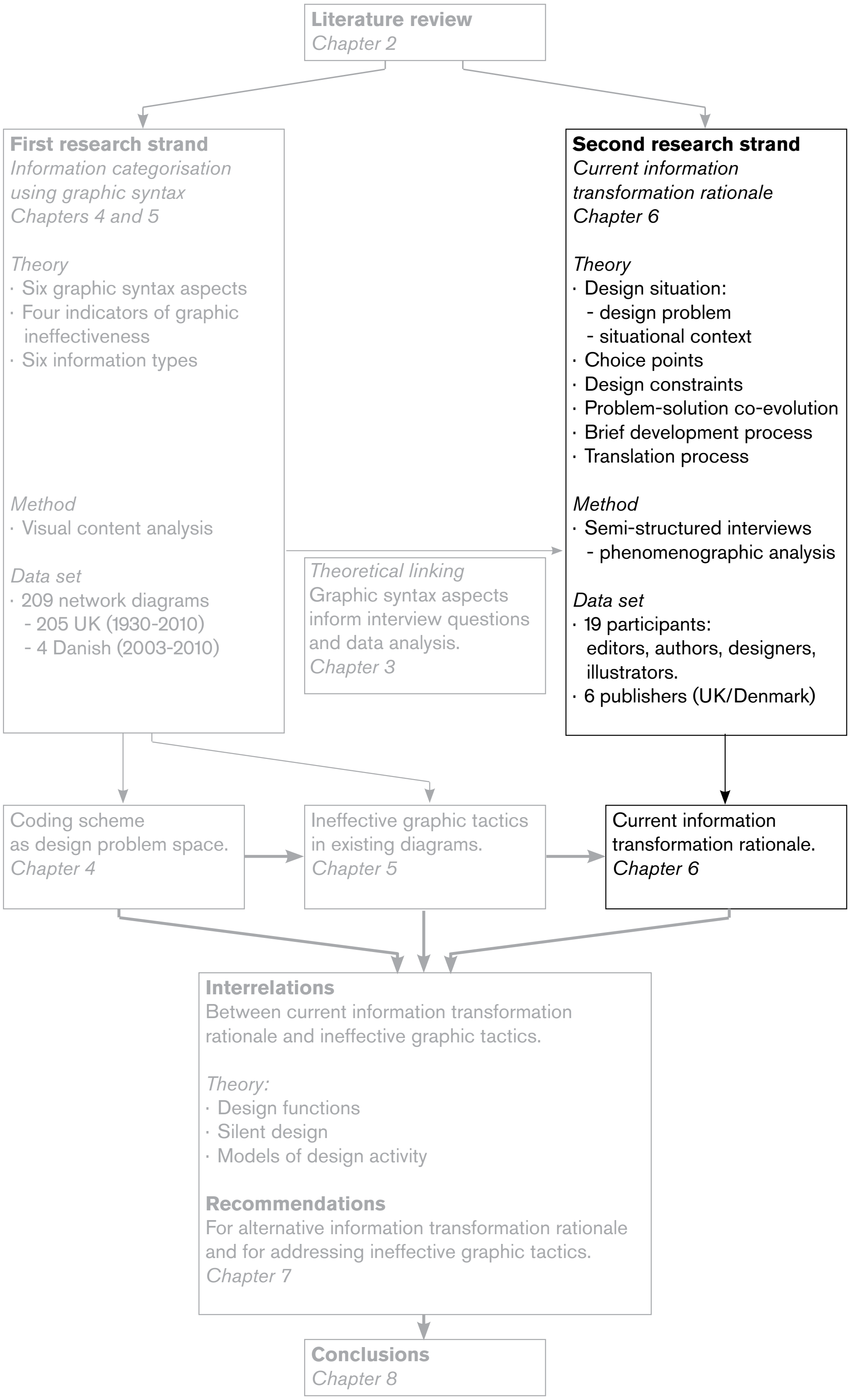
The 29 ineffective graphic tactics were summarised in tabular form, including their effect on the content proper message and interrelations to other coding variables. This revealed three general effects on the content proper message resulting from the ineffective graphic tactics: ambiguity about the nature of included elements, their mutual roles, and the essential circulating element.

In the future this table can be used as a tool for information design practitioners, illustrating the interrelations between graphic syntax aspects and the three general effects on the content proper.

The visual content analysis revealed the extent of the ineffective graphic tactics in a sample of four Danish ecological cycle network diagrams.

This chapter concludes that the 29 ineffective graphic tactics represent ineffective sub-problem-solution parings in an ill-defined design problem space for ecological cycle network diagrams.

6 Current information transformation rationale


Literature review
Chapter 2
First research strand
Information categorisation using graphic syntax
Chapters 4 and 5
Theory
· Six graphic syntax aspects
· Four indicators of graphic ineffectiveness
· Six information types
Method
· Visual content analysis
Data set
· 209 network diagrams
- 205 UK (1930-2010)
- 4 Danish (2003-2010)
Theoretical linking
Graphic syntax aspects inform interview questions and data analysis.
Chapter 3
Second research strand
Current information transformation rationale
Chapter 6
Theory
· Design situation:
- design problem
- situational context
· Choice points
· Design constraints
· Problem-solution co-evolution
· Brief development process
· Translation process
Method
· Semi-structured interviews
- phenomenographic analysis
Data set
· 19 participants:
editors, authors, designers, illustrators.
· 6 publishers (UK/Denmark)
Coding scheme as design problem space.
Chapter 4
Ineffective graphic tactics in existing diagrams.
Chapter 5
Current information transformation rationale.
Chapter 6
Interrelations
Between current information transformation rationale and ineffective graphic tactics.
Theory:
· Design functions
· Silent design
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Recommendations
For alternative information transformation rationale and for addressing ineffective graphic tactics.
Chapter 7
Conclusions
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Contents

6 Current information transformation rationale

6.1 Introduction

In the *first research strand* of this research enquiry, the ecological cycle network diagram was traced through its theoretical context, identifying the information categorisation in exiting visual output. This chapter presents the findings based on the *second research strand*. The case of visual output is now traced through the professional practice context to identify the process that generates ecological cycle network diagrams. This investigation was guided by questioning which features within design practice in educational publishing may affect the rationale when transforming a manuscript and visual references into a published diagram.

6.1.1 Professional practice context and design situation

Design practice in educational publishing is in this research enquiry seen as a simultaneous creative and management process. Several participants are here involved in an organic network of decision-making when performing the design task (Dorst, 1997), *ie,* designing an ecological cycle network diagram in the given practical setting and within a given time [section 2.4.2.2, p. 44]. To identify and analyse the participants' reasoning when defining, planning, and composing a visual output, the professional practice context is here seen as a part of a design situation. The individual publisher's practical setting then represents the situational context which surrounds the ill-defined design problem [figure 1.3, p. 13].

The situational context is identified, at a meta-level, from the interview data, by identifying features attended to, variation in approaches, and reasoning guiding the decision-making at choice points (Schön, 2006) in the brief development and translation processes. This facilitates two analytical perspectives of the design situation. Firstly, a cross-sectional view identifies features that may affect the decision-making; secondly, a process oriented view identifies how participants navigate among the features when designing an ecological cycle network diagram (Cross, 2000; Dorst and Cross, 2001).

The features within the situational context which may affect the decision-making represent external constraints on the design problem (Lawson, 2006). By identifying the organising principles (Rowe, 1987) as well as the participants who are involved in decisions, this research enquiry reveals detailed nuances in the decision-making. When later integrating the research findings [chapter 7], such nuances facilitate further analysis of the delegation of informal and formal responsibilities within educational publishing. In turn the delegation of responsibility reveals the models of design activities applied within this professional practice context [section 2.4.5.2, p. 52]. The outcomes of the *second research strand* thereby enable analysis of interrelations between design decision-making in relation to the occurrence of ambiguities in ecological cycle network diagrams. Practically, this analysis was facilitated by a phenomenographic analysis method.

6.1.1.1 Phenomenographic data analysis

Phenomenographic analysis usually includes two steps, yielding two outcomes: 1) description of variation found within a data set, an activity which identifies 'categories of description', and 2) organisation of these categories into a hierarchical structure, resulting in a phenomenographic 'outcome space' (Bowden, 2000) [section 3.4.2, p. 91]. In this research enquiry the 'outcome space' – here research findings or research outcome – is pre-structured around the brief development and translation process (Crilly, 2005) as well as the choice points within these processes (Schön, 2006) [section 2.5.2.1, p. 56]. The 'categories of description' identified by this research enquiry are the features attended to and the variation in approaches described at each choice point. These findings provide the cross-sectional analytical view of the design situation. The process oriented perspective is facilitated by identifying different chronological sequences of the choice points, dependent on different approaches to the design process. This chronological view here replaces a hierarchical structure of the 'outcome space', to detect how the participants navigate the design situation, *ie,* the co-evolution of the problem-solution space (Dorst and Cross, 2001) over time [section 2.4.2.2, p. 44]. The outcomes from this analysis represent composites of variation in approaches to information transformation within the data set. This provides a snap-shot of the current information transformation rationale as reflected by the interviewees at the time of the interviews [section 3.4.2. p. 91].

6.1.1.2 Presentation of analysis findings in this chapter

The analytical focus for the *second research strand* makes for a relative dense chapter. The section following this [section 6.2, p. 223] presents the theoretical framework applied for identifying the design situation including the organising principles at each choice point and their interrelations. Existing theoretical models (Cross, 2000; Dorst and Cross, 2001; Lawson, 2006) are here synthesised and expanded with detail to enable identification of the participants' reasoning guiding the decision-making for individual graphic tactics as well as analysis of their interrelations. Then follows a description of variation within the data set, a measure to ensure a reliable research outcome [section 6.3, p. 228], and a brief description of the general publishing process, to provide context for the brief development and translation processes [section 6.4, p. 233].

Sections 6.5 [p. 236] and 6.6 [p. 272] form the main part of this chapter, presenting the research findings from analysing the brief development and translation process respectively. These findings enable a discussion of the professional practice context, and information transformation rationale as identified through this research enquiry [section 6.7, p. 289], including additional external constraints, such as communication links between participants (Zeisel, 1988; Lawson, 2006; Crilly, 2005) [section 6.7.3, p. 292].

6.2 The design situation

The design situation is in this research enquiry seen as consisting of several significant choice points. The information transformation rationale is here identified by revealing the organising principles at significant choice points in the brief development, and translation process, and their interrelations. For this purpose, existing theoretical models (Cross, 2000; Dorst and Cross, 2001; Lawson, 2006) are synthesised and expanded with detail. This enables identification of the reasoning guiding decisions for individual graphic tactics and analysis of their interrelations.

6.2.1 Choice points

Within an ill-defined design problem exists a parallel relationship between a problem and solution space [section 2.4.2.2, p. 44]. These spaces are bridged by pairing (sub)-problems with their potential (sub)-solutions (Cross, 2000; Dorst and Cross, 2001). Choice points are in this research enquiry defined in terms of the relationship between these problem-solution spaces:

- A point in the design situation, at which a participant is faced with a significant problem, sub-problem, or set of sub-problems; the choice point as represented in the problem space. For example, deciding on one diagram type from other types of graphic representation.
- The possible solutions, sub-solutions, or set of sub-solutions chosen at each point, *eg,* choosing a network diagram.

A participant's decision at a choice point thereby represents the problem-solution pairing at that particular point. Two steps of analysis were here taken to identify the rationale behind the problem-solution pairings at choice points in the brief development and translation stage – the choice points identified from existing literature [2.5.2.1, p. 56].

6.2.1.1 Steps in analysis centred around choice points

This data analysis involved two general steps to facilitate both the cross sectional and the process oriented analytical perspective of the design situation. Firstly, the identified choice points were applied as separate units of analysis, structured in a generalised process sequence. This general sequence reflects the structure of sections 6.5 and 6.6 [figure 6.1].

Brief development process [section 6.5]						**Translation process** [section 6.6]	
[A] Diagram type	**[B]** Biological content	**[C]** Specifying artwork brief	**[D]** Sketch diagram	**[E]** Brief evaluation	**[F]** Visual references	**[G]** Translation of brief	**[H]** Evaluation of diagram proof
[6.5.1]	[6.5.2]	[6.5.3]	[6.5.4]	6.5.5]	[6.5.6]	[6.6.1]	[6.6.2]

Figure 6.1: Choice points A-H presented in general sequence.

At each choice point were identified:

1. Variation in approaches to deciding problem-solution pairing, and the reasoning guiding each approach – from interview data.
2. The relation of the identified approaches to external and internal design constraints (Lawson, 2006), and Archer's solution options (1964/1984) and the room for manoeuvre: open design situation, inevitable solutions and broken up field of freedom, the latter here described as a flexible room for manoeuvre [section 2.4.3.1, p. 48].
3. The relation of the identified approaches to the co-evolving problem-solution spaces (Dorst and Cross, 2001).

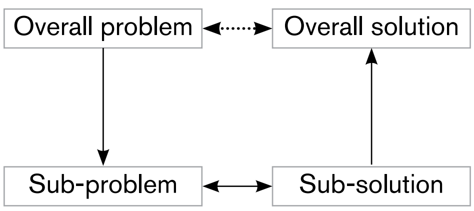
The cross-sectional view of the design situation here reveals the organising principles at each choice point. By analysing these principles in relation to the problem-solution co-evolution (Dorst and Cross, 2001), the process oriented view revealed how the participants navigate among the features in the design situation, and how decisions at one choice point affects decisions at interrelated choice points. These findings in turn uncovered variation in the sequence of choice points, dependent on the different approaches [sections 6.5.7, p. 265 and 6.6.3, p. 283]. Within each of these different process sequences the transfer of 'focus and fitness' as the problem-solution co-evolve may be identified (Dorst and Cross, 2001). To uncover the detail and nuances of these interrelations, the problem and solution spaces are here seen as comprising both an overall and a sub-dimension.

6.2.2 Overall and sub-dimension of problem and solution space

The analytical focus in this research enquiry requires detailed analysis of decision-making in relation to individual graphic tactics within each graphic syntax aspect. This analysis is here enabled by synthesising the models from Cross (2000) and Dorst and Cross (2001):

- Cross (2000) [figure 6.2] includes an overall problem space, overall solution space, sub-problem space, and a sub-solution space as nodes. The arrows represent shifts in the designer's focus (Cross, 2000: 42).
- In Dorst and Cross (2001: 11) [figure 6.3] the sub-dimension is implicit in the problem space 'P(t)' and solution space 'S(t)' nodes. The arrows represent evolution in time or movement of the designer's focus and transfer of 'Fitness'. 'Fitness' here refers to identifying a 'partial structure' of the problem space and using it to start defining the solution space, or, at later stages, to refining the thus far defined solution space (2001: 12).

The dotted line attribute is added here to illustrate how the movement of the designer's 'Focus', in the overall dimension in figure 6.2 correlates to the three arrows transferring 'Focus, Fitness', across time, in figure 6.3.



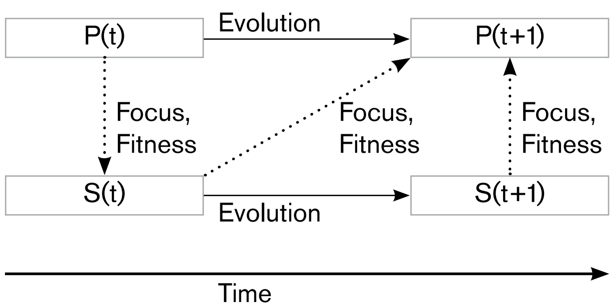


Figure 6.2: Visual adaption of Cross (2000: 42)
Figure 6.3: Visual adaption of Dorst and Cross (2000: 236)

The synthesis applied in this thesis relates to identification of the transfer of 'Focus, Fitness', within the sub-dimension, *ie,* the co-evolution of the sub-dimension in time. This reveals how the problem and solutions spaces within each dimension are bridged. In this thesis the sub-dimension refers to the six graphic syntax aspects, each with additional sets of sub–problems, *ie,* the graphic tactics [section 2.1.3.1, p. 28]. The overall dimension refers to the graphic strategy, *ie,* the network diagram type and biological content, as summarised in table 6.1.

Cross (2000)	As represented in this thesis
Overall dimension	Graphic strategy: Deciding network diagram type and biological content. [Section 2.1.3.1]
Sub-dimension	Graphic tactics: Decisions regarding each of the six graphic syntax aspects and the options within each; illustrated by the visual content analysis coding scheme. [Figure 4.51, p. 154]

Table 6.1: The overall and sub-dimension of the design problem investigated here.

In terms of 'Fitness', the analytical focus in this thesis is limited to the interchange of information in the form of design constraints.

6.2.3 Design constraints

Internal and external design constraints are features which determine the room for manoeuvre within the design situation (Lawson, 2006; Archer, 1964/1984) [section 2.4.3.1, p. 48]. Decisions at one choice point may here act as external or internal constraints on the problem-solution pairing at interrelated choice points. To enable analysis of such interrelations in this research enquiry, the detail in describing design constraints and transfer of 'Fitness' needs extension, following the synthesis of Cross (2000) and Dorst and Cross (2001). This extended detail relates to sub-problem-solution pairings at one choice point and how they may affect the room for manoeuvre when pairing sub-problems and sub-solutions at interrelated points. This detail is provided by defining the status of different sub-problem-solution pairings.

6.2.3.1 Sub-problem-solution pairings

The visual content analysis in this research enquiry revealed interrelations between individual graphic tactics, *eg*, how the information type applied in an arrow label influences the represented arrow type. To analyse how such graphic interrelations are considered, when pairing sub-problems and sub-solutions, a distinction is here made in the status of a design decision. This definition is based on the implication of a design decision for interrelated choice points. Three distinctions in the status of a design decision are here defined, identified from the interview data set:

- Sub-problem-solution pairing is a **final solution**
  For example, a font choice specified by the book design template.
- Sub-problem-solution pairing is a **tentative solution**
  These are suggested or drafted sub-solutions which are subject to evaluation and potential iteration.
- Sub-problem is **transferred as a sub-problem**
  This includes aspects which are intentionally or unintentionally transferred without consideration or decision-making. For example, visual attributes of arrows which exist theoretically as a sub-problem at the point of an author's sketch but may not be considered until the translation process.

Detecting the status of sub-problem-solution pairings provides deeper detail about the co-evolution of the sub-problem-solution spaces. Furthermore, the analysis reveals the delegation of formal and informal responsibilities in the decision-making process in relation to individual graphic tactics.

The two sections presented so far have presented the structure of data analysis and positioned the outcome in its theoretical context. The reliability of this interview data analysis is anchored partly in the outlined synthesis and application of theoretical concepts, *ie,* whether the outcome represents a reliable snap-shot of the current information transformation rationale. In addition to these measures, the reliability of a phenomenographic data analysis is based on measuring the sample variation (Adams, *et al,* 2009).

6.3 Sample variation

Identifying the variation within the sample of interviewees is a crucial part of phenomenographic analysis. In this research enquiry, sample variation ensures that the composite views, from which the research outcome is formed, represent a reliable map of the professional practice setting. Here the sample variation is measured in relation to participating publishers, composition of the individual participant 'sets' from each publisher, and the interviewees' level of professional experience.

6.3.1 Measures of sample variation

When analysing and plotting the interview data in phenomenographic analysis, each conducted interview provides a snap-shot of the individual interviewee's reflection on his or hers own practice. The resulting research outcome represents a composite of these individual snap-shots, *ie,* a 'meta-reflection-on-practice' (Cherry, 2005; Schön, 2006). An important measure for providing a reliable meta-reflection is the variation represented by the participants who provide the individual reflections on their practice. Relevant points of variation for the analytical focus in this enquiry include two overall measures – professional and personal variation – each with several sub-measures, as summarised in table 6.3.

Professional variation	**Personal variation**
Geography: UK or Danish publisher	Gender
Publisher focus: Range of subject covered	Age
Curriculum level: A-level or Secondary	Background
Domain: Internal or externally employed	Years in publishing related work
Formal role: Editor, author, designer, illustrator	Years at company

Table 6.3: Measures of sample variation in this research enquiry.

Each measure of variation here relates to different aspects of the analytical focus in this research enquiry:

- The geographic variation – Denmark and the UK – enables detection of whether approaches to deciding problem-solution pairings, and the information transformation rationale itself varies across this geographic boundary.

- Variation in the output from participating publishers – in relation to subject ranges and curriculum levels – identifies the reliability of the research findings in relation to the 14-18 year age groups [section 6.3.1.1 below].
- Variation in the participant 'sets' relates to interviewing editors, authors, designers, and illustrators at each publisher – ensuring reliability in relation to the interview strategy of investigating along the critical path [section 2.5.3.1, p. 58].
- Variation in the participants' level of experience provides a general context for the research outcome [section 6.4, p. 233].

6.3.1.1 Publisher output in relation to curriculum level and subject range

The six publishers are here distinguished according to the range of curriculum subjects and levels covered; creating three categories as summarised in table 6.4.

	UK 1	UK 2	UK 3	DK 1	DK 2	DK 3
One subject/one level					■	
Several subjects/one level				■		
Several subjects/both levels	■	■	■			■

Table 6.4: Sample variation in publishers' output in relation to subject range/level.

An interesting difference is found between the two countries; the Danish market accommodating specialist biology educational publishers – DK2 – whereas the UK market consists mainly of bigger conglomerates covering several curriculum subject and levels. However, both publishing markets are seeing continuous corporate merging activity. For example, Pearson acquired Heinemann (UK) in 2007, whilst Egmont (DK) in 2003 became prime shareholder of Alenia (DK). Such corporate developments within the professional practice context underscores the status of the research findings contributed here as a snap-shot reflecting the time of research.

6.3.1.2 Composition of participant 'sets'

Table 6.5 shows the 19 interviewees distributed across formal role and publishers. The composition of each 'set' of participants are central to providing reliable snap-shots of design practice within individual publishers.

	UK 1	UK 2	UK 3	DK 1	DK 2	DK 3
Head of science			▪ ■	╲	▪ ▒	╲
Senior publisher	▪ ■		▪ ■	▪ ▒	▒	
Senior editor	▪ ■	▪ ■	▪ ■	▒	■	
Author	▒	▒	■	■	■	■
Design manager			▪ ■	╲	╲	╲
Graphic designer	▒	▒	■	■		
Illustrator	╲	▒	▒	╲	╲	■

▪ Interviewee is internal, rather than external, staff at publisher.
■ Interviewee represents one publisher.
▒ Interviewee represents two roles or publishers.
☐ Participant not interviewed.
╲ Formal role does not exist/no illustrator participated in diagram design.

Table 6.5: Participant 'sets' across publishers and formal roles.

Several overlaps appear in the sample. In the UK, one author, designer, and illustrator each work for two or more publishers respectively. They are included in both 'sets' of participants, as they discussed variation in approaches between the companies. In Denmark, some people perform a range of formal roles, performed by different individuals in the UK due to larger business scale. The general formal responsibilities of these roles, as described by the interviewees, are summarised in table 6.6[1].

Formal role	**Responsibilities in relation to *ecological cycle network diagram*, as described by interviewees**
Senior publishers/ Commissioning editors	· The publisher's main link to the market · In contact with government bodies, keeping up-to-date with proposed legislation changes. · Develops publishing proposals and tests proposals in schools [approaches include focus groups with pupils, questionnaires, interviews with teachers] · Hires the authors. · General overview level, rather than detail, on individual publications

1 Interviewees also mentioned roles which are peripherally involved in the brief development and translation process: marketing, sales, head of science publishing, managing editor, proof reader, series editor, media research, and external consultant/reviewers.

Formal role	Responsibilities in relation to *ecological cycle network diagram*, as described by interviewees
Editor/ Senior editor/ In-house editor/ Freelance editor	· Responsible from content development/editorial stage till press. · Checks author drafts and the 'look and feel' of the book: language style, presentation, artwork, and textual content. · Checks artwork briefs. · Briefs the designers/illustrators [by email or face-to-face].
Copy editor	· Checks spelling and grammar of the textual content.
Author	· Writes body text. · Submits artwork briefs to editor. · Evaluates proofs.
Design manager	· Responsible for team of senior designer, designers, pre-press coordinators, budget management, and supplier relations. · Hands-on involved mainly in the overall role of driving the sample design 'look and feel' in relation to branding and series identity.
Designer/illustrator	The designer and illustrator roles may be distinguished in relation to the type of output: *Book designer* · Sample book design: the book's visual concept and layout. · Book template: electronic template of sample design. · Book design: laying out the book content in the template. · Diagrams with text, arrow, container shape *Illustrator* · Pictorial elements: illustrator · Integral metric spaces: illustrator

Table 6.6: Outline of formal roles as described by interviewees.

In addition to variation in the number of formal roles within a publisher, the responsibilities may be informally delegated to the participants within each individual process; depending on publisher size, individual skills, interests, and mutual personal relations within the processes. For example, both editors and authors may apply what can be considered 'design' skills [discussed in chapter 7]. Likewise the boundary between the designer and illustrator roles – in relation to the diagram design – is blurred. Book designers may be responsible for either, or both, the sample book design, the layout template, and the final book design, *ie,* laying out the manuscript and artwork in the template. Simultaneously, the book designer is in charge of diagrams with text/arrow/container shapes. In other cases part of a diagram may be further out-sourced to an illustrator who provides either a complete diagram, the pictorial elements and/or background. If the illustrator is responsible for the pictorial elements and/or background only, then the book designer composes the final diagram through organising the elements and adding arrows. These differences are discussed in detail in section 6.6.1 [p. 272]. Book designers are selected by the commissioning editor or, at bigger publishers, the in-house design manager. All interviewed designers and illustrators had long-standing working relations with the publishers and all work with several different publishers.

6.3.1.3 Variation in level of experience

The level of experience represented by the interviewees is summarised in appendix 10, rather than in a table here, due to the nature of the descriptions. One author, for example, mentioned 20 years' experience, but had lost count of publications. Some authors mentioned roles as co-authors or head authors, and others mentioned years of experience which included progression through several roles, *eg,* from publishing secretary to senior editor. Appendix 10 then provides a general context for this snap-shot of current practice. An additional description of the general context is provided before presenting the analysis findings for each choice point. This context relates to locating the brief development and translation processes within the general publishing process stages as reflected in the interview data.

6.4 General publishing process sequence

The stages in the publishing process identified in the literature review – synopsis, editorial, design, production, and distribution/sales [section 2.5.2, p. 55] – are reflected in the interview data gathered. However, some nuances between the UK and Denmark exist, which may affect the brief development and translation processes. This provides a general context for the research findings from the *second research strand*.

6.4.1 Brief development and translation processes

The general book development activities from manuscript to final publication are similar across the participating publishers. However, all interviewees stressed the flexible and organic nature of processes for individual textbooks, influenced by different levels of iterations, delegation of skills, and subsequent participant relations for included activities.

Synopsis stage

A difference in the level of constraints imposed by the exam specifications results in different delegation of skills between Denmark and the UK. The UK book structures are tightly determined by the exam specifications, as is evident from the identical section headings across different text books. In the Danish synopsis stage, the exam specifications mainly serve as guidelines. A more flexible approach to the content structure is evident here in the space devoted to the ecological cycle subject; ranging, *eg,* from one chapter (Piekut *et al,* 2007) to an entire book (Bjerrum *et al,* 2005) for the 15 year age groups. The increased flexibility leaves the Danish authors greater room for manoeuvre in relation to content structure, resulting in co-authors working in close co-operation, *eg,* regularly meeting in person. The UK authors, on the other hand, may have the content pre-delegated by the publishers, or series editor, and work individually. The nature of the synopsis stage affects the editorial stage within which the brief development process is found.

Editorial stage

Authors, in both countries, generally develop the artwork brief simultaneously with the manuscript leaving the brief development as an integral part of the editorial stage. In Denmark, the closer co-operation between authors accommodates informal brief evaluations – between co-authors – before submitting the artwork brief to the editor. One unique case in the UK sees co-operation between author and book/diagram designer at this stage – the designer actively developing the briefs. This approach similarly adds an informal brief evaluation and iteration before submission to the editor.

Dependent on the individual approach, the author's specification of the artwork brief may include a diagram sketch. Once submitted, the artwork brief is evaluated by a senior editor/copy editor – depending on the publisher – which may result in iterations between author and editor. In some cases the author submits a visual reference with the artwork brief. The editor may create a diagram sketch from these or choose to enclose visual references with the brief submitted to the designer or illustrator. This brief development process is thereby based entirely within the editorial process stage, with the authors as brief originators and senior/copy editors as the evaluator. However, the editors may also actively develop the brief content. Meanwhile, the translation process is found within the overall design stage of the book development.

Design stage

The translation of the artwork brief commences when the designer/illustrator receives the artwork brief from the editor. Danish editors may meet face-to-face with designers to discuss the written briefs, UK editors usually e-mail the brief to the designers/illustrators. The designer/illustrator translates the brief and submits his or hers visual output for the editorial team and authors to evaluate the diagram proofs. The first version of the diagram is usually included in the second book proofs. UK publishers mentioned up to four proof stages for diagrams whereas some Danish diagrams reached nine proofs.

The variation in approaches to developing and translating the artwork brief depends on the author's approach to the brief and the nature of iteration within the process. This variation is here identified by first analysing each choice point as a separate unit and identifying the participants involved in sub-problem-solution pairings. The choice points are then organised in the different process sequences found within the data set.

6.5 Brief development process

The brief development process here comprises the specification and evaluation of the artwork brief and any visual references included. This section presents the findings from plotting the interview data across the six choice points [A-F] relating to the brief development process, here seen as separate units of analysis. For each choice point, firstly, the identified variation in approaches to deciding problem-solution pairing is revealed and the reasoning guiding each approach; secondly, the identified approaches are analysed in relation to external and internal design constraints (Lawson, 2006), Archer's solution options (1964/1984), and the co-evolving problem-solution spaces (Dorst and Cross, 2001). Finally a sub-section follows [section 6.5.7, p. 265] in which the choice points are arranged in the identified process sequences to discuss the problem-solution co-evolution in the brief development process.

6.5.1 Choice point A – deciding on diagram type

Brief development process [section 6.5]						**Translation process** [section 6.6]	
[A] Diagram type	**[B]** Biological content	**[C]** Specifying artwork brief	**[D]** Sketch diagram	**[E]** Brief evaluation	**[F]** Visual references	**[G]** Translation of brief	**[H]** Evaluation of diagram proof
[6.5.1]	[6.5.2]	[6.5.3]	[6.5.4]	6.5.5]	[6.5.6]	[6.6.1]	[6.6.2]

The findings for choice point A include two overall considerations when choosing a network diagram, mentioned explicitly and consistently by all participants. These include the role of visuals in the textbook, namely the general purpose and the curriculum purpose, which relate to the specific type of diagram [figure 6.4]. Sub-categories of variation within these two purposes are indicated in bold type when first discussed in the following sub-sections.

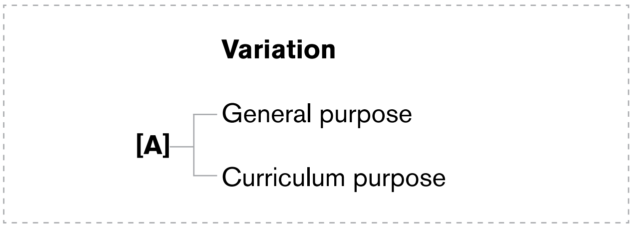


Figure 6.4: General variation at choice point A

6.5.1.1 General purpose of ecological cycle network diagram

Visuals are generally included in biology textbooks to clarify or amplify the verbal context, each type of visual having a specific purpose. Photos and illustrations, for example, may provide 'real world' context for a subject or demonstrate a laboratory experiment setting. Although some interviewees described photos as 'looking pretty' or 'beautiful', all stressed a functional, rather than aesthetic purpose in textbooks. Frequent reference was made to a **compositional function** – breaking up the text for visual variation on a page – and to the **explanatory function** in relation to the body text:

> 'Overall the purpose with visuals is to supplement the text and in some cases maybe also tell an extra story. At the very least, they should amplify the text. We definitely try to avoid to include visuals which are purely decoration.' *#9 Danish editor*

In terms of the explanatory function, the body text-diagram relationships which were consistently described reflect Schriver's complementary and supplementary text image relationships (1997) [section 4.3.2.1, p. 107]. The relationships are considered for accommodating different learning styles, *eg,* visual or verbal orientation. This in turn reflects the general positive physiological and cognitive effects of diagrams: making spatial relationships meaningful, pattern recognition, and simultaneous processing of information (Winn, 1987: 160) [section 2.2.1, p. 30]. All authors and editors agreed that the use of textbooks depends on the student's ability and time devoted to the subject. Authors and most editors expect students to read the body text as part of their homework, and maybe in class, and teachers to use the books when planning lessons. In general, a larger audience is anticipated for diagrams, than for the body text:

> 'It's our experience that a lot of students look at the figures and image captions, and don't have time to read the body text or maybe don't understand the text. And we'd like to support this, so the stronger students absorb the combination of body text, visuals, and captions, and the less strong students get something from just looking at the figures and maybe reading the captions.' *#4 Danish author*

So an ecological cycle network diagram complements the body text for some pupils but plays a more central role as main carrier of information for others. In particular the role as a main carrier of information highlights the importance of syntactic effective and unambiguous diagrams.

The nature of the content proper also influences the diagram type representing the **content proper-diagram relationship**. The network diagram was explained consistently as an obvious choice for visualising the interrelations in ecological cycles. This relationship is directly linked to the curriculum purpose of the network diagram type.

6.5.1.2 Curriculum purpose of ecological cycle network diagram

Within the data set, the exam specifications and exam questions were found to consistently dominate the authors' and editors' reasoning when choosing the network diagram type in both countries:

> 'That carbon cycle diagram is taken from the 9th grade written exam because a lot of teachers use it for tests.' *#16 Danish author*

> '…There are some standard diagrams that you really need in every book…[because] it's a very core concept that's always being tested.' *#5 UK senior editor*

This reasoning is interesting given that only one exam specification – the OCR in the UK – prescribes a 'nitrogen cycle diagram' (OCR, 2007: 83) [section 2.5.4.1, p. 61]. The choice of diagram here appears severely constrained by expectations to exam questions. Given this apparent convention of including ecological cycle network diagrams in biology text books and exams, this particular visual output may be described as a staple in the 'design lexicon'

(Gillieson, 2008: 107) of educational publishing; *ie,* a recurring visual feature across different publishers and years. The inclusion in a 'design lexicon' highlights the significance of this particular visual output and further underscores the need for precise information categorisation.

6.5.1.3 Deciding on diagram type [A]: variation

Figure 6.5 summarises the identified variation in approaches to problem-solution pairing when choosing the diagram type. It is appropriate to stress that this tree diagram – and those presented for proceeding choice points – shows the *variation* within the data set. An individual participant may only attend to some of the features, may iterate, and attend to the features in a different order than as presented. This is indicated by the circular arrow.

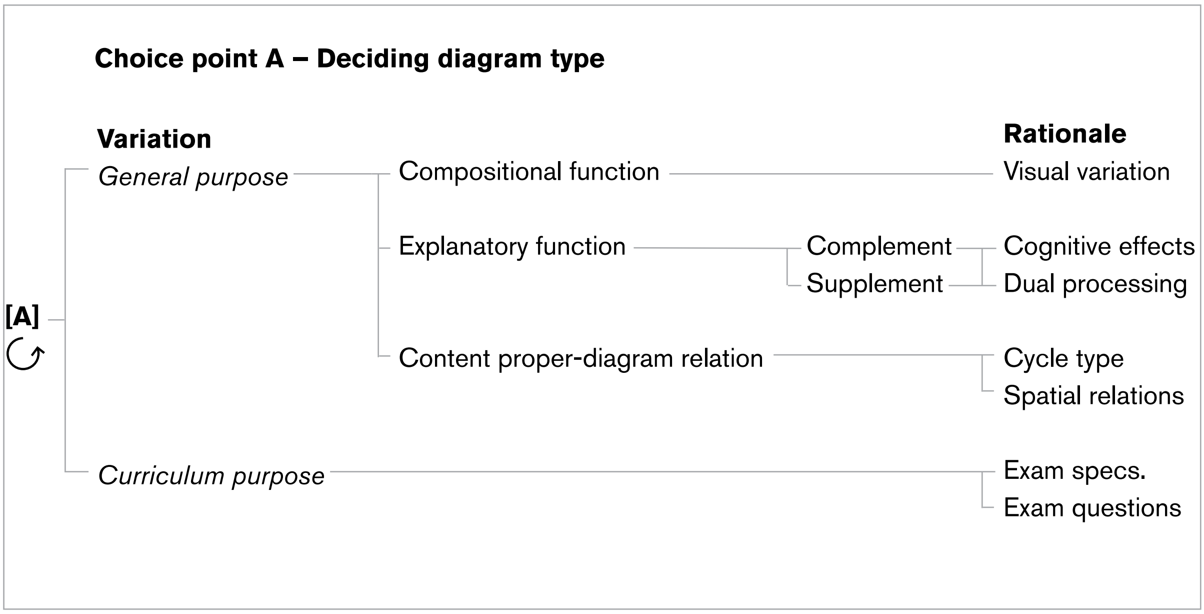


Figure 6.5: Variation in approaches to problem-solution pairing at choice point A.

Deciding the diagram type represents the problem at this choice point; the network diagram here the solution. The decision-making is externally constrained by the general reasons for including visuals in textbooks – compositional and explanatory functions – however, the most significant constraint is the exam specifications and exam questions which also informs the features of the cycle to focus on, *ie,* the content proper-diagram relations. Such standard choice of the ecological cycle network diagram – in textbooks, revision guides, and the actual exams – highlights the importance of applying precise information categorisation using graphic syntax to avoid the potential for repeated ambiguous messages in all three elements of the pupils' learning.

In terms of the problem-solution co-evolution, the problem setting process starts with a given overall solution; the network diagram representing an inevitable and final solution. This in turn defines the sub-dimension of the problem space, transferring the six graphic syntax aspects as a set of sub-problems – and internal constraints – to interrelated choice points, as well as decisions about the biological content.

6.5.2 Choice point B – biological content

Brief development process [section 6.5]						**Translation process** [section 6.6]	
[A] Diagram type [6.5.1]	**[B]** Biological content [6.5.2]	**[C]** Specifying artwork brief [6.5.3]	**[D]** Sketch diagram [6.5.4]	**[E]** Brief evaluation 6.5.5]	**[F]** Visual references [6.5.6]	**[G]** Translation of brief [6.6.1]	**[H]** Evaluation of diagram proof [6.6.2]

With the network diagram as a curriculum-led given solution, the interrelated decisions may be considered simultaneously and include iterations, dependent on the further approach. The decisions about biological content [B] relate directly to the curriculum purpose and the explanatory function found at choice point A [figure 6.5, p. 239]. Two general approaches were here identified in the data set [figure 6.6]:

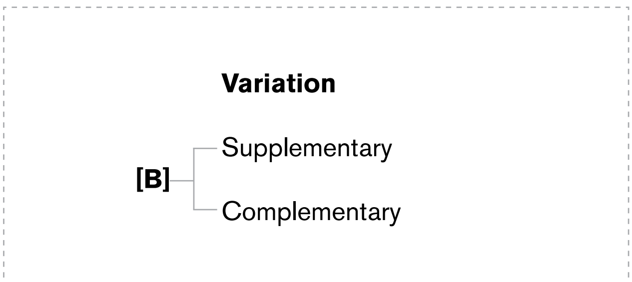


Figure 6.6: General variation at choice point B

6.5.2.1 Supplementary information

Generally in the textbooks the body text outlines the biological content, describing principles and interrelations. The key concepts are then transferred as basic diagram content, based on the exam specifications:

> 'The diagram content is biologically correct information. The information are facts which they have to know.' *#11 Danish author*

> 'The diagram content is just something they have to learn. That's decided by the curriculum.' *#10 Danish editor*

A supplementary diagram includes the key concepts from the body text, hence exam specifications. In the UK, the verbal content of OCR[2] exam specifications can be traced literally in related ecological cycle network diagrams. Such a level of external constraint results in an inevitable solution for the biological content. Other UK and Danish diagrams reflect more flexibility at this choice point by complementing the body text.

6.5.2.2 Complementary information

Increased flexibility in the exam specifications may result in complementary diagrams. Complementary diagram content may augment the body text content in several ways. Different angles, zooms, or cross sections provide **visual deepening**, *eg,* often seen in water cycle diagrams, [*eg,* appendix 9, figure A9·2]. The diagram content may also be **biologically broadened** by adding concepts. One author anticipated the use of the diagram in a lesson by making the diagrams 'talkable':

> '…So you can talk about it. This is where we use our experience a lot and look at what can be included, and things are regularly added, for example, "let's add a tractor in the background because then we get the whole agricultural context"…this may also build up to other biological themes in other chapters.' *#16 Danish author*

The room for complementing the body text is hedged, however, by some publishers preferring another supplementary approach:

2 An Awarding body.

> ‘We have an informal rule that you can’t have a lot of things in a diagram which aren’t described in the text because then the text and diagram don’t make sense together. So when I say that the diagram has to work on its own, then I don’t mean that it includes loads of things not mentioned in the text, that can’t ever happen.’ *#13 Danish editor*

> ‘I’ve done several books where I’ve used diagrams to explain something that I don’t explain in the text at all. Here we deliberately did that. We used whole pages to say things, *eg,* a whole page to [visually] describe muscle structure, where we’ve decided we won’t re-iterate that into the text. But that’s relatively rare. People don’t like you doing that...I think, there’s been some research that shows that students don’t learn so well just from annotated diagrams, which I find slightly surprising. I know teachers love this because we get photocopy rights from it.’ *#2 UK author*

It is beyond the scope of this thesis to discuss learning merits from diagrams only, compared to a text and diagram complementation. Research from instructional science is simply noted here as a possible constraint on the level of complementing the body text. A publisher’s general approach to visuals in textbooks also influences the decisions about the complementary content in a diagram. Some emphasise the visual content, some rely on more traditional text-biased structures. This is evident from variation in column width devoted to each type of visual element in different publishers’ output.

6.5.2.3 Biological content [B]: variation

Figure 6.7 [next page] summarises the variation found for choice point B.

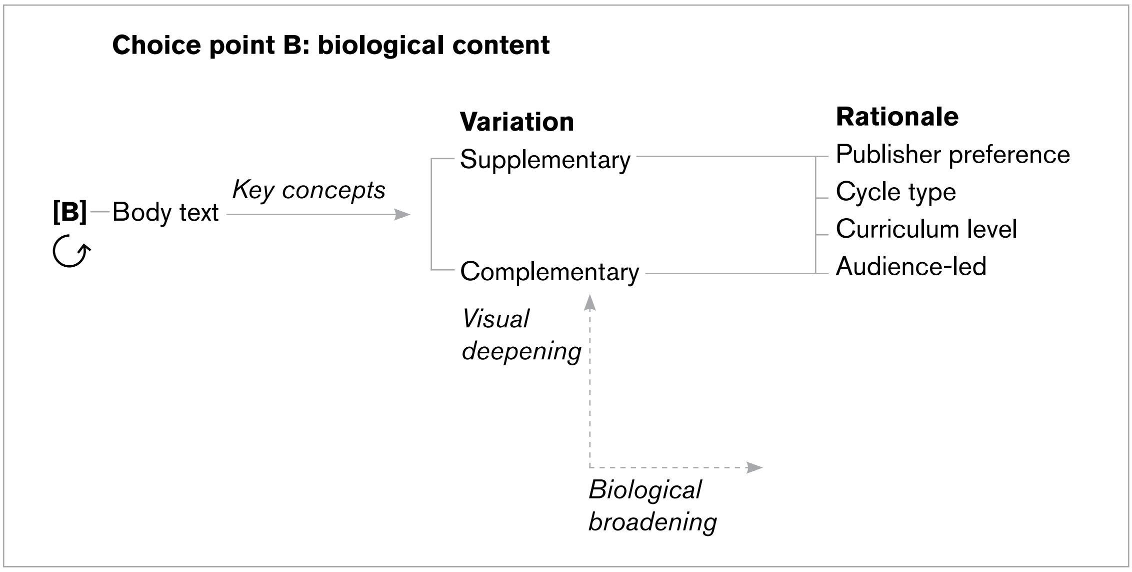


Figure 6.7: Variation in approaches to problem-solution pairing at choice point B.

The biological nature of the ecological cycle type forms the underlying external constraint when deciding the biological content. The exam specifications also significantly influence the decisions, even providing the overall solution in some supplementary approaches. A complementary information approach – either broadening or deepening – represents a tentative solution. The level of flexibility here is externally constrained by the publisher's formal or informal preferences. In relation to the problem-solution co-evolution the biological information is identified as either a final or tentative solution. The chosen information types thus form part of the internal constraints at interrelated choice points – with tentative sub-solutions subject to evaluation. This is dependent on the author's approach to specifying the artwork brief.

6.5.3 Choice point C – specifying artwork brief type

Brief development process [section 6.5]						**Translation process** [section 6.6]	
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]
Diagram type	Biological content	Specifying artwork brief	Sketch diagram	Brief evaluation	Visual references	Translation of brief	Evaluation of diagram proof
[6.5.1]	[6.5.2]	[6.5.3]	[6.5.4]	6.5.5]	[6.5.6]	[6.6.1]	[6.6.2]

When specifying the artwork brief, the author engages in the sub-dimension of the problem space – represented by the six graphic syntax aspects – *ie,* individual graphic tactics [table 6.1, p. 226]. The artwork brief form is a standard template, developed and supplied by the publisher. The required specifications include commitment to several sub-solutions at this choice point: text content, font, font size, caption headings, a tentative visual of the intended diagram, and aesthetics in relation to the book concept or sample book design. Some of these problem-solutions pairings may have been decided at page layout stage, namely the visual and typographic attributes:

Visual attributes

The colour palette for arrow and container shapes may be externally constrained by the book sample design, previous editions or the book series, *ie,* decided in the synopsis stage. This approach leaves the shape and size attributes to be decided in the translation process. Alternatively, all visual attribute decisions are transferred as sub-problems to the translation process.

Typographic attributes

The font choice and node-arrow distinction are decided as part of the sample book design. In the UK the choices are externally constrained by publisher preference and the editorial team. Danish authors are consulted on the typographic style, and the designer who develops the sample book design is also in charge of the final book design. This increases the room for manoeuvre and iteration when detailing the typographic attributes in the translation process [section 6.6·1·3, p. 275]. Some publishers prefer consistent use of upper and lower case in diagrams, whereas some prefer the graphic tactics of nondistinctive nodes and connectors. The reoccurring criterion when considering type was readability in relation to audience level, *ie,* accessibility. Some UK editors also mentioned 'projectability', *ie,* if the font reads well when projected onto a white board in the class room.

Decisions about the remaining graphic syntax aspects – node and connector syntactic roles, pictorial objects, arrow types, and verbal syntax – depends on the author's approach to specifying the brief. Four general brief types were found within the data set, based on the approach to specify the intended diagram in the artwork brief form, as submitted to the editor. Brief type a) relates to re-using an existing diagram without adjustments; b) involves adjustment of biology content or terminology; c) involves a text description and any visual references; d) may include a draft or detailed sketch (figure 6.8). The variation found at this choice point is here essential for identifying different chronological sequences of choice points within the data set.

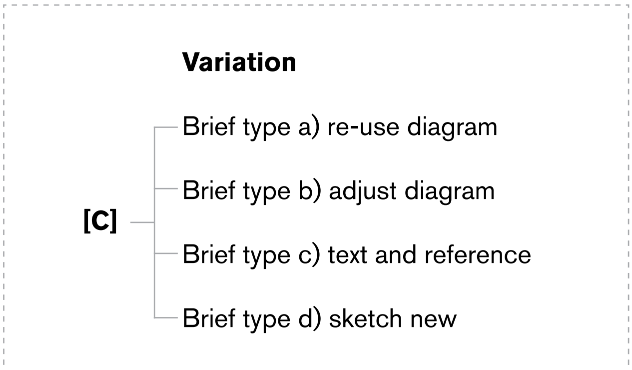


Figure 6.8: General variation at choice point C

6.5.3.1 Brief type a) re-use diagram from existing book

Identical diagrams can be found in some UK textbooks for different awards, which are part of the same series (*eg,* Fullick *et al*, 2001a and b). Such re-use is mainly driven by financial considerations [figure 6.9]. In such inevitable solutions the overall problem equals the overall solution, including all sub-problems and sub-solutions [figure 6.10].

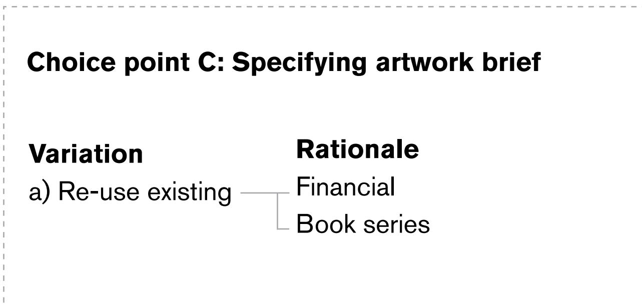


Figure 6.9: Variation for brief type a).

Brief type a) **Reuse existing diagram**

Overall dimension	*Status of decision*
Diagram type	Final solution
Biological content	
Sub-dimension	
Nodes/Connectors	
Arrow types	
Pictorial objects	
Visual attributes	
Typographic attributes	
Verbal syntax	

Figure 6.10: Status of design decisions for brief type a) as submitted to editor.

6.5.3.2 Brief type b) adjust existing diagram

Several editors and authors described 'tinkering with', 'tarting up', or 'adjusting' existing diagrams to fit the body text's context and the **visual style** of their publication:

> 'Often they [the briefs] say "re-use figure x from another book". As you can see, when we have a decent artwork that shows the concept, we tend to not spend the money to get it redone, we get it tarted up to suit the market, based on an older version.' *#2 UK Senior editor*

This approach is applied in books within the same series aimed at different levels – *eg*, Foundation and Higher – adjusting the diagram's **biological content** or **biological terminology**:

> 'So all I did was say "can we use that diagram?" and they've made slight changes but you can see it's similar, the nitrogen cycle, it's almost identical. It's very similar, isn't it? Based on the same diagram. So that was my instruction there, please insert figure 28, page 83 from this book…[but] I wouldn't mind using the word decomposition on Higher but generally reluctant to use it at Foundation Level.' *#7 UK author*

Financial considerations here appear as the underlying factor, however visual adjustment may be driven by external constraints such as a book series visual style, curriculum level, or the content of the body text [figure 6.11].

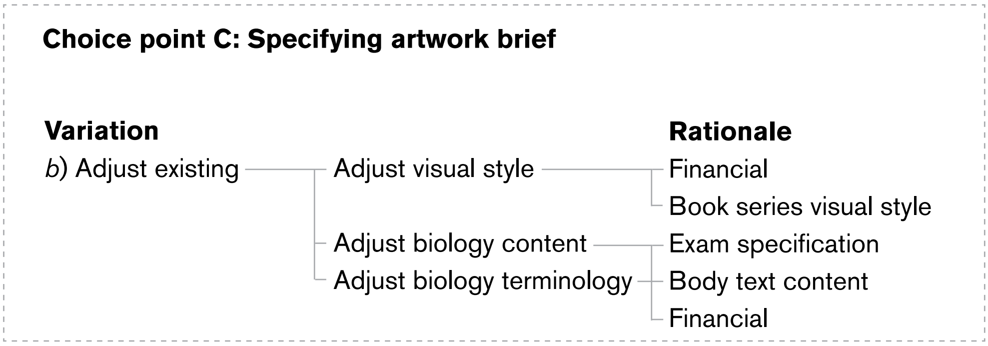


Figure 6.11: Variation for brief type b).

If the author adjusts the biological content or terminology, these aspects represent tentative sub-solutions as they are subject to evaluation and possible iteration. When adjustments are limited to the visual style, the decisions at this choice point are also tentative sub-solutions for five of the six graphic syntax aspects. However the visual attributes may have been specified by the book template [figure 6.12].

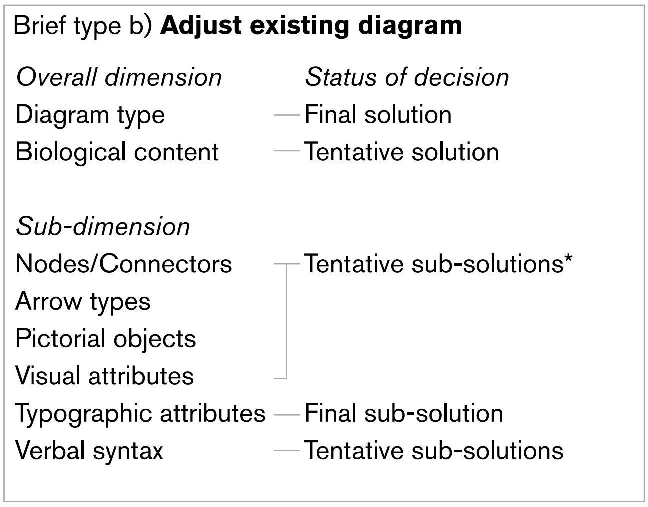


Figure 6.12: Status of design decisions for brief type b), as submitted to editor.
*Visual attributes are decided at synopsis stage or during translation.

6.5.3.3 Brief type c) Text and references only

In contrast to the previous two, brief type c) relies on **text description only** or **text and references**:

> 'What we get from the authors varies depending on their comfort with different levels of visual presentation. Some just writes "a diagram

that shows the nitrogen cycle", and that's their brief. Ideally we get a bit more than that. And then it's the editor, or quite often a freelance copy editor, who takes whatever the author's done, whether it's a text or a description, and will work that up into a brief you can give to an artist. That's usually a drawing, so they can copy and embellish, but with detailed instructions on labelling *etc*… but some of our authors do really nice artwork briefs that the artists can just copy and you just need to annotate a couple of parts to make it clear. But it does vary immensely.' *#2 UK Senior editor*

Enclosed references may be used as a basis for a new diagram:

> '… Others [references] have been found in different books and they say, "It's this principle we want sketched", and then we find a different way of doing it.' *#10 Danish editor*

The role of visual references receives closer scrutiny in section 6.5.6 [p. 260]. Brief type c) is externally constrained by the author's drawing skills, or aim at creating an original diagram [figure 6.13]. This brief type results in transferring the majority of the problem space as sub-problems for interrelated choice points; with the exception of any pre-defined visual and typographical attributes [figure 6.14].

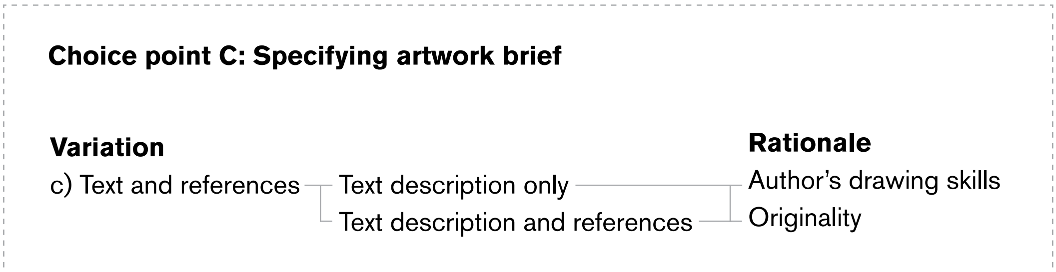


Figure 6.13: Variation for brief type c)

Brief type c) **Text and reference**

Overall dimension	*Status of decision*
Diagram type	Final solution
Biological content	Transferred as sub-problem
Sub-dimension	
Nodes/Connectors	Tentative sub-solutions
Arrow types	
Pictorial objects	
Visual attributes	Tentative sub-solutions*
Typographic attributes	Final sub-solution
Verbal syntax	Transferred as sub-problem

Figure 6.14: Status of design decisions for brief type c) as submitted to editor.
*Visual attributes are decided at synopsis stage or during translation.

The editor quoted above, making reference to artists copying the specified diagram, highlights the inevitability of the solution later briefed to the designer. This is discussed in section 6.5.7, [p. 265]. The editor's role in re-working the author's specified diagram is discussed in section 6.5.5 [p. 256].

6.5.3.4 Brief type d) sketch diagram

In place of existing references, authors may include a sketch of their intended diagram in their brief:

> 'We did a lot of the figures ourselves because it's often hard to find an existing figure that shows exactly what we want. Then we do a hand-drawn sketch with stick men and stuff like that.' *#16 Danish author*

Where drawing skills may limit the detailing of a sketch, some authors deliberately limit the detailing to a **draft sketch**, to ensure more flexibility for the designer:

> 'We've had a principle about that if we do too detailed sketches or do a photocopy from an old book, which we also do, and say that this is what we want illustrated, then often they just do the old one, or turn it around or something like that. And that's not fun, is it? We'd like them to interpret the old one and make it more exciting or how can I explain it.' *#11 Danish author*

Two authors in the data set stand out in relation to visual skills. One author draws **detailed sketches** using Microsoft Word. Another case, unique within this data set, sees an author and designer/illustrator – with a science teaching background – working closely together from the beginning. The designer here develops the sketch to a final solution before submitting to the editor. If the author is working with a different book designer, then minor adjustments may be made to the sketch. The rationale for sketching a new diagram reflects that for brief type c), only here the visual skills are enabling rather than constraining the decision [figure 6.15].

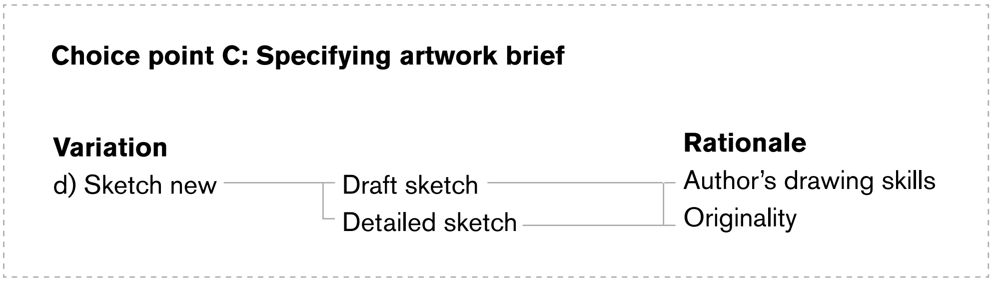


Figure 6.15: Variation for brief type d).

The nature of the sketches mentioned within the data set may be described as 'frozen' (Whyte *et al*, 2007, here from Klopp, 2010: 4). Here all the content is defined, leaving only aesthetic considerations as 'fluid'. This results in a 'prescriptive sketch'[3] (Ferguson, 1992, here from Van der Lugt, 2001: 39) where the author or editor prescribe their decisions for later translation. Although a detailed diagram sketch may represent the final solution, the sketches are identified in this thesis as tentative sub-solutions [figure 6.16, next page], due to both approaches being subject to evaluation and possible iteration.

3 Fergusons' two other types are 'thinking sketch' – plotting thoughts in and individual thinking process –and 'talking sketch' – sharing thoughts by visual means in collaborative thinking process.

Brief type d) **Sketch new diagram**

Overall dimension	*Status of decision*
Diagram type	Final solution
Biological content	Tentative sub-solution
Sub-dimension	
Nodes/Connectors Arrow types Pictorial objects	Tentative sub-solutions
Visual attributes	Tentative sub-solutions*
Typographic attributes	Final sub-solution
Verbal syntax	Tentative sub-solutions

Figure 6.16: Status of design decisions for brief type d) as submitted to editor. *Colour and texture visual attributes are decided at synopsis stage or during translation process.

The sketching of a new diagram is analysed in further detail as choice point D [section 6.5.4, p. 253] after an overview of the four brief types.

6.5.3.5 Specifying artwork brief [C]: variation

Figure 6.17 summarises the four brief types identified from the data set.

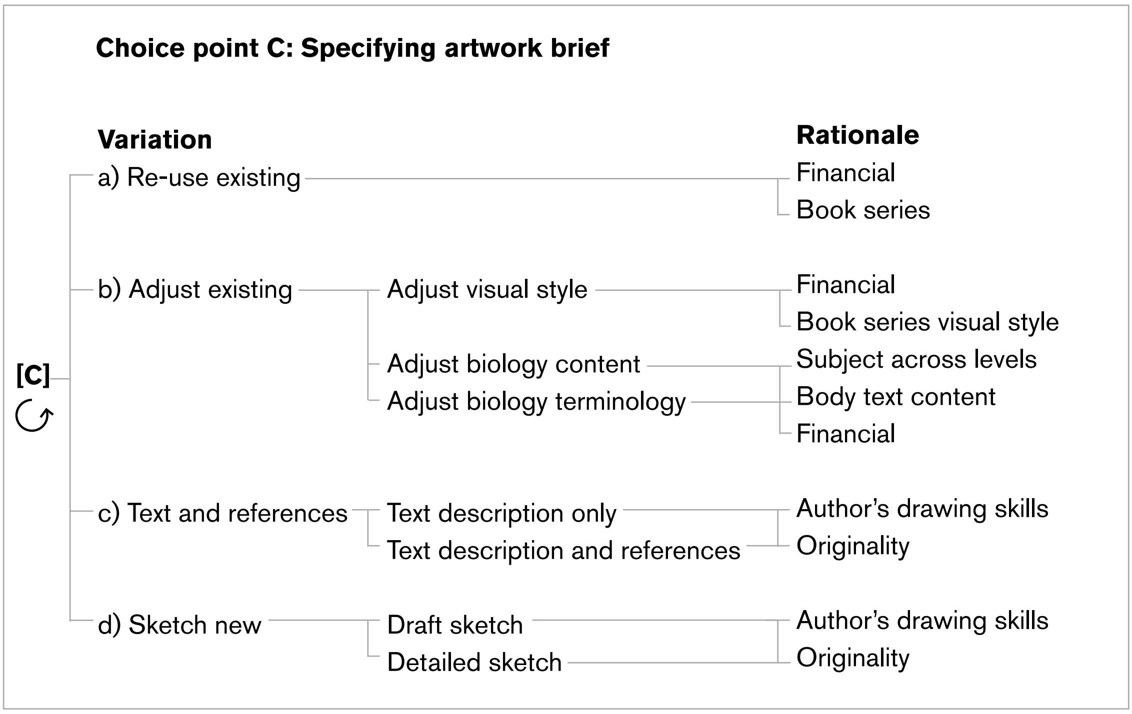


Figure 6.17: Brief types a)-d), identified in the data set

At choice point C the author faces decisions of how to specify the intended ecological cycle network in the artwork brief. Therefore this choice point requires decisions about the sub-dimension of the problem space. The author's response at this choice point, has essential effects for the editor's response, and activity when evaluating the brief, and consequently the sequence of choice points in the individual transformation process. These effects are discussed when presenting the different sequences in section 6.5.7 [p. 265], and in relation to the brief evaluation [E] [section 6.5.5, p. 256] after outlining the approaches to sketching a new diagram.

6.5.4 Choice point D – Sketch diagram

Brief development process [section 6.5]						Translation process [section 6.6]	
[A] Diagram type	[B] Biological content	[C] Specifying artwork brief	**[D] Sketch diagram**	[E] Brief evaluation	[F] Visual references	[G] Translation of brief	[H] Evaluation of diagram proof
[6.5.1]	[6.5.2]	[6.5.3]	**[6.5.4]**	6.5.5]	[6.5.6]	[6.6.1]	[6.6.2]

Choice point D is a sub-problem within choice point C: the sketching of an ecological cycle network diagram as part of specifying brief type d). Several sub-problems and solutions have already been paired at this point, as either final or tentative solutions: the network diagram, biological content, and possibly the colour coding, and typographic attributes. This section presents the various approaches to deciding syntactic roles, arrow types, and verbal syntax [figure 6.18] after outlining the author's general reasoning when sketching.

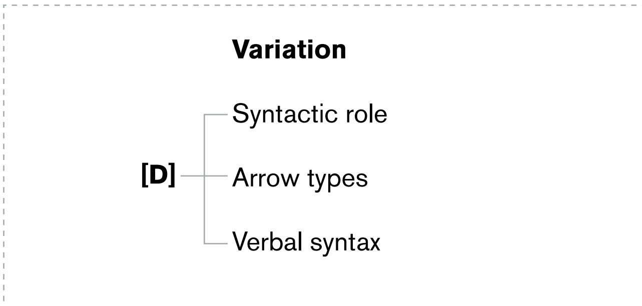


Figure 6.18: General variation at choice point D.

6.5.4.1 General reasoning when sketching new diagram

The sequential organisation of graphic objects in an ecological cycle network diagram is naturally constrained by the biological nature of the content. The room for manoeuvre left for the author includes the relative ordering of sub-cycles within the diagram, *eg,* 'photosynthesis-respiration' in relation to 'death-decomposition'. All interviewed authors described their considerations about graphic structure and detail as guided by intuition, based on their teaching experience and use of diagrams in lessons:

> 'It doesn't go through a logical pattern... I did spend twenty years teaching. So everything in there I've taught students and presented them as visual information. And you get a lot of feedback from students, so you quickly know what they understand and what they don't understand...'
> *#1 UK Designer*

> 'It's based on my background as a biology communicator. "Will this work or not in a lesson?" I've got an instant feeling for that… if I'm in a lesson, "can I use this?" Can I use the way we interpret it, can I follow the arrows, can I talk about what's in play here, and simultaneously give the students an overview that says, "what are we actually talking about here"' *#16 Danish author*

This room for manoeuvre is also hedged by the curriculum level:

> 'It's probably to do with all of us having the same education. So we say "As a minimum it needs this". Then, if you've got a higher level chemistry or maths, you can expand it by showing, *eg,* that when the process runs this way, in this figure, then it produces energy. That could be illustrated in different ways… and you could go deeper and say in reality it's not like this, it's electrons that are running around and make it happen. And then you can add the organisms' role.' *#14 Danish author*

With this underlying reasoning outlined, the following two sub-sections present the variation in approaches to deciding problem-solution pairing for nodes and connectors, and arrow types [section 6.5.4.2], and verbal syntax [6.5.4.3, p. 255].

6.5.4.2 Nodes, connectors, and arrow types

When composing the ecological cycle network diagram, authors as a standard intend to categorise organisms and matter using **nodes** and processes as **connectors**. However, several authors highlighted arrows showing, *eg,* the reading direction in a diagram – **conceptual connectors** – or chemical energy – **movement between** – in the diagrams present during the interviews. The authors may thereby consciously include several arrow types. All authors referenced constructivist learning theory as a rationale when including pictorial objects, *ie,* making the subject more concrete through everyday context.

The sketching of nodes, connectors, arrow types, and their relative spatial positioning represent tentative sub-problem-solution pairings; subject to later evaluation and possible iteration.

6.5.4.3 Verbal syntax

The verbal syntax is decided by the author(s). At one extreme this is tightly regulated by the exam specifications:

> 'They [an endorsing[4] Awarding body] wanted the actual wording in here to be identical to the wording in the specs.' *#7 UK author*

The demand of this **inflexible** approach results in an inevitable sub-solution prescribed by the external constraint. The **flexible** approach leaves the verbal syntax decisions to the author(s) resulting in tentative sub-solutions:

> 'The sketch was discussed over e-mail and in our meetings. And then it's about going into the smallest details in the sketch, and read every word, and every sentence, several times over. Nothing is left to coincidence.' *#11 Danish author*

The author's evaluation criteria, when deciding on verbal syntax, were described as biological accuracy and audience reading level, informed by practical teaching experience. No mention was made of distinguishing information categories through use of verbal syntax.

6.5.4.4 Sketch diagram [D]: variation

When an author decides to sketch a new diagram, the available room for manoeuvre is limited. The network diagram is an external 'given' and the biological information partly inevitable; in turn dictating the general linking of concepts. The author's decisions are thereby aimed at the sub-dimension;

4 In the UK publishers may pitch to become endorsed by an Awarding body, its preferred partner, or go against the officially endorsed series. Endorsement hands the final acceptance of book content to the board's evaluators.

where in some cases the visual and typographic attributes are pre-specified. This leaves only the selection of graphic objects and decisions about nodal or connector roles, leading the author to categorise arrow types and specifying the verbal syntax (figure 6.19).

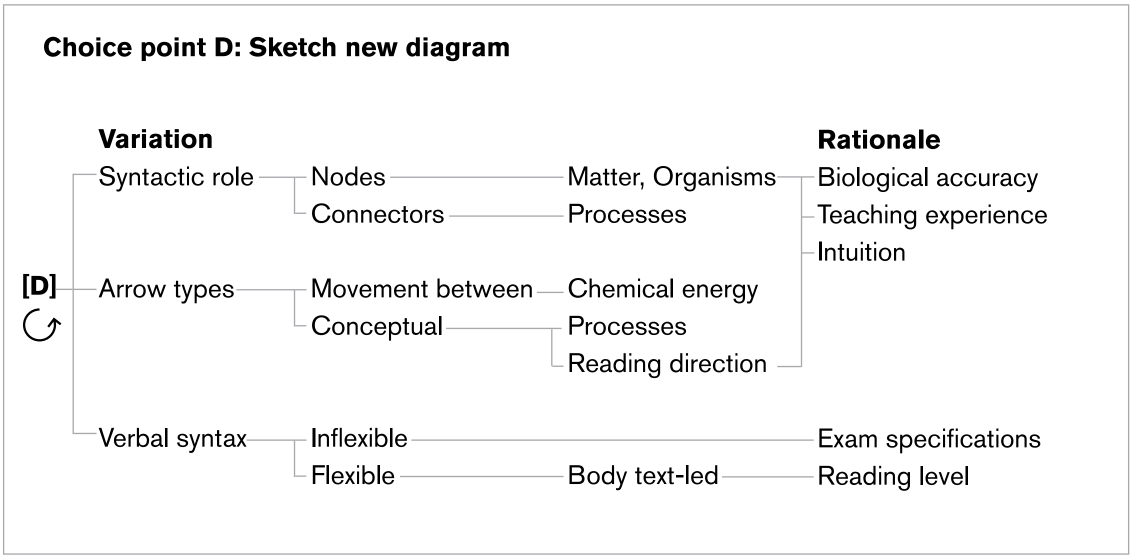


Figure 6.19: Variation in approaches to problem-solution pairing at choice point D.

The room for manoeuvre when sketching a diagram is hedged mainly by the exam specifications and biological accuracy; the decisions further guided by intuition, based on practical teaching experience. Sub-solutions for all three graphic syntax aspects are transferred to the interrelated choice points as tentative sub-solutions, subject to evaluation, and iteration; except inflexible verbal syntax, which is a final sub-solution.

6.5.5 Choice point E – brief evaluation

Brief development process [section 6.5] | **Translation process** [section 6.6]

[A] Diagram type [6.5.1]
[B] Biological content [6.5.2]
[C] Specifying artwork brief [6.5.3]
[D] Sketch diagram [6.5.4]
[E] Brief evaluation [6.5.5]
[F] Visual references [6.5.6]
[G] Translation of brief [6.6.1]
[H] Evaluation of diagram proof [6.6.2]

The author submits the specified artwork brief to the editor. The editor's approach to evaluation depends on the type of brief submitted and the status of the decisions represented by each brief type [figures 6.10, 12, 14 and 16]. Brief type a), re-use existing diagram, is accepted as a final solution. With brief type b), c), and d) the editor proceeds to evaluate and possibly further develop the author's tentative solution into the final brief [see quote by #2 UK senior editor, p. 248]. When evaluating – and developing – the brief, the editor generally clarifies the brief instructions for the designer, and the diagram content for the pupil reader group [figure 6.20].

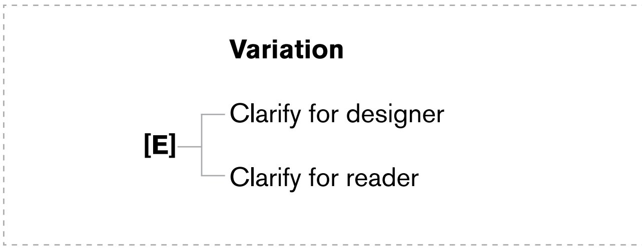


Figure 6.20: General variation at choice point E

Clarifying the design includes the biological details and labelling [section 6.5.5.1]; clarifying for the reader relates to the body text-diagram relation, the reading level and the level of detail [section 6.5.5.2, p. 258].

6.5.5.1 Clarify for designer/illustrator

The editor's approach when clarifying for the designer or illustrator depends on the brief type and includes adding or deleting details to a re-used existing diagram, re-drawing, and clarifying the author's sketch, or – in the case of brief type c) – actually specifying the intended ecological cycle network diagram, based on the text and reference. One designer summarises this aspect of the editor's role in the overall transformation process:

> 'The visuals start from the authors, he scribbles something and shows it to the editor, who trims it and makes it easier for me to understand. So first the author explains it to the editor, then she explains it to me, and then we all explain it to the pupils.' *#12 Danish designer*

The editor ensures that the **biological details** in the sketch are clear and that the **labelling** is readable, aiming at a clearly specified diagram which the designer/illustrator can translate without further instructions:

‘It has to be very precise in relation to the designer or illustrator because the designer isn’t a biologist. And you’ve got some points, some times it works well, and sometimes it doesn’t because we misunderstand each other. Or we haven’t communicated the right things. It’s something we use a lot of time on. As a publisher the visual side of things is so important.’ *#13 Danish head of publishing*

When developing brief type c) – text and references – the editor is in charge of specifying both biological content [B] and the sub-dimension [C and D]:

> ‘There can be a drawing saying ‘the water cycle’ and typically a copy from an older book, their own or others, it can be from all kinds of places. First of all this means that if I get 100 artwork briefs for one book and they are sourced from 15 different books then the style is different and maybe the water cycle from one book is simple and from another it’s more complicated, then it’s me who decides what goes in and what is edited out.’ *#14 Danish editor*

Thus the editor progresses through the approaches identified in sections 6.5.2-4, sketching the diagram in detail whilst evaluating and clarifying in relation to the readers.

6.5.5.2 Clarify for readers

Both editors and authors consistently described three themes as dominating the editors’ evaluation focus: the **explanatory function, reading-level**, and the **level of detail**[5]:

> ‘[I check the brief] according to the specifications. According to what we wanted, what we were covering in the content. Because sometimes authors have suggestions for art works. But they are far too complicated. So you have to make sure that it’s simple enough and clear enough.’ *#6 UK editor*

The level of detail criteria applies both to the amount of information

5 At bigger publishers one development editor may look at the overall amount of information whereas the copy editors check for consistency in terminology between body text and diagram.

included and number of graphic objects:

> ‘There can’t be too much information in there. There has to be as little as possible whilst still communicating the message…a lot of times the authors have to compromise their biological knowledge, because we just can’t have all of it included …then the pupils wouldn’t get the message…I tightened the text in that diagram a lot, it just wasn’t simple enough.’ *#10 Danish editor*

> [On mentioning to authors that the number of arrows in a diagram is confusing], ‘I do, just because I don’t have a science background, I’m quite a lay person, so I can come to it with a complete fresh pair of eyes. I can say to my authors, “I know you know a lot about the carbon cycle, but this may be a bit confusing”.’ *#3 UK editor*

All three criteria aim at ensuring that the tentative overall solution – the diagram specified in the brief – enables a final overall solution – the published diagram – which meet the general purposes identified in choice point A [section 6.5.1.2, p. 238].

6.5.5.1 Brief evaluation [E]: Variation and reasoning

The approaches to brief evaluation are summarised in figure 6.21.

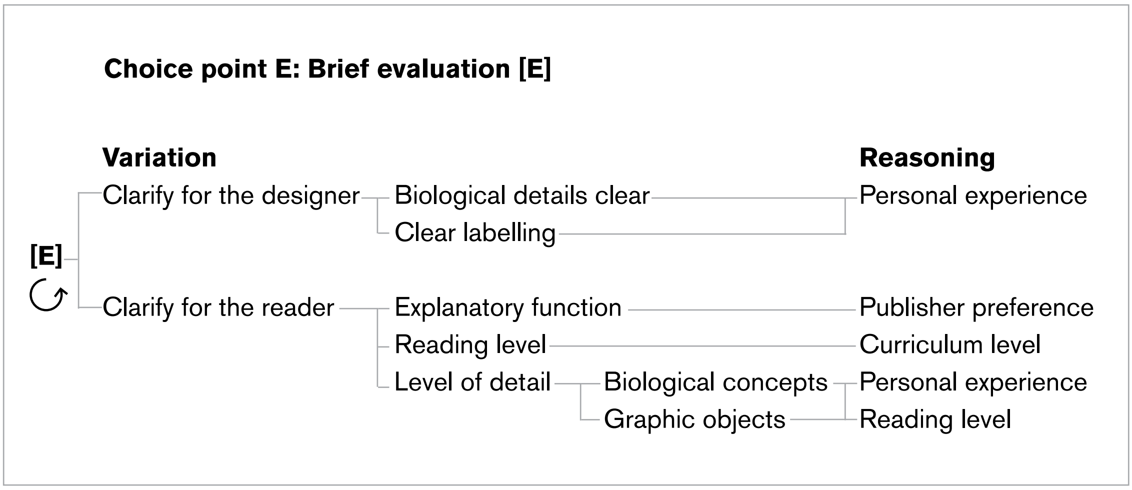


Figure 6.21: Variation in approaches to problem-solution pairing at choice point E.

The brief evaluation [E] presents the editor with the transferred sub-solutions of varying status. The task is now to ensure a tentative overall solution, providing clear instructions for the designer and readers. The general and curriculum purposes, identified in choice point A, are external constraints for decisions about the six graphic syntax aspects at this choice point. An additional underlying external constraint is the editor's practical experience and level of science knowledge. Appendix 10 describes the varied backgrounds of editors in the data set: 30 years as A-level science teacher, PHD in science, a literature degree, a production editor, and an English literature degree. The intricate interrelation between professional experience, general purposes of visuals in text books, and sub-problem-solution pairings, illustrate the iterative and complicated nature of decision-making within the information transformation rationale. Depending on the brief type, the author or editor may enclose visual references to help the clarification.

6.5.6 Choice point F – visual references

Brief development process [section 6.5]						Translation process [section 6.6]	
[A] Diagram type [6.5.1]	[B] Biological content [6.5.2]	[C] Specifying artwork brief [6.5.3]	[D] Sketch diagram [6.5.4]	[E] Brief evaluation 6.5.5]	**[F] Visual references [6.5.6]**	[G] Translation of brief [6.6.1]	[H] Evaluation of diagram proof [6.6.2]

Visual references may be supplied by the author, then used by the editor when specifying the brief, or the references may be selected by the editor to provide additional clarification for the designer. Significant for the focus in this enquiry are the types of references submitted and the role they play in the brief development. This results in presenting the findings for this choice point as F_1 and F_2. In F_1, the visual references are identified as intra- or inter-subject class and subject level in relation to the specified ecological cycle network diagram [figure 6.22].

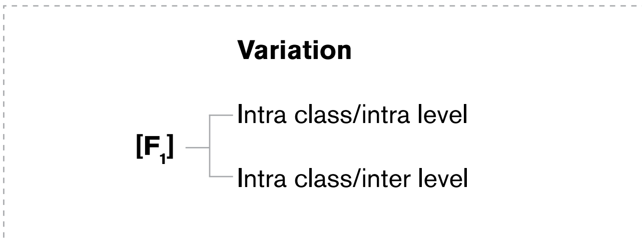


Figure 6.22: Variation at choice point F_1: subject class and level of references.

In F_2 the roles of visual references are identified in relation to the brief types. These roles range from representing the final solution, tentative solution, or simply inspiring, and clarifying the graphic tactics [figure 6.23].

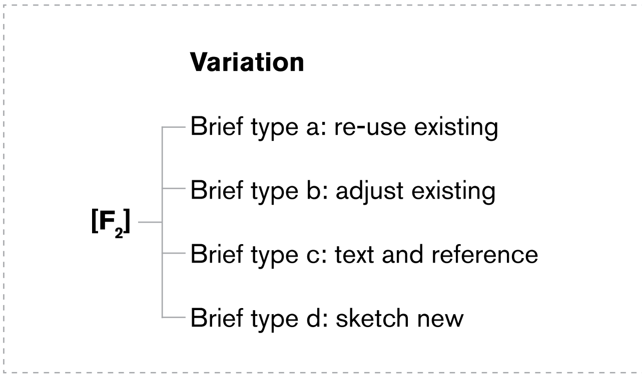


Figure 6.23: Variation at choice point F_2: brief types deciding the role of reference.

6.5.6.1 Types of visual references

Commissioning editors generally refer to competitors' books for reference to book concepts, *eg,* approaches to structure, context, and general visual style. The types of references informing the brief development are limited to what Crilly (2005: 133) describes as **intra-class**[6], *ie,* diagrams from the same category, here ecological cycle network diagrams [figure 6.23, next page]. Such standardised reference class reflects the inevitable diagram type. Simultaneously, the visual references may be **intra-levels**, *ie,* same audience level, from the authors' or publishers' own books or official exam papers. **Inter-level** visual references, on the other hand, are sourced from outside the individual author/publisher's sphere, from higher audience levels. Each participant explained how they may combine different types from the general list depending on the role.

6 As opposed to inter-class references, *ie,* to other types of diagrams or visual explanations in general.

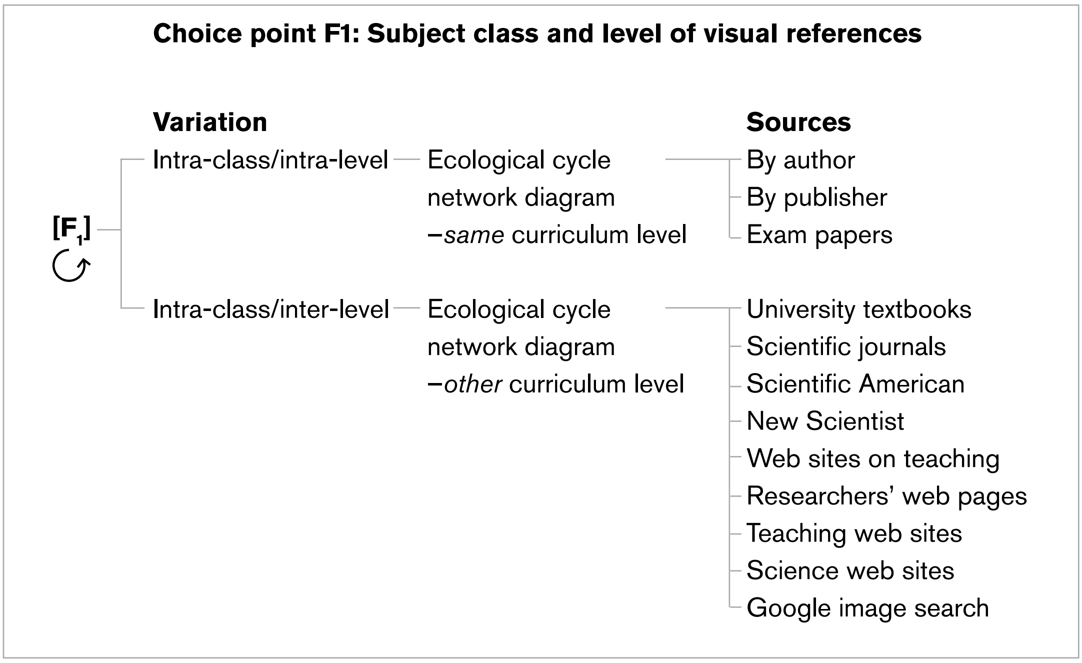


Figure 6.24: Choice point F_1: Types of visual references

6.5.6.2 Role of references in brief development process

The visual references are selected by different people and play different roles, depending on the brief type. The limited variation in the class and level of visual references has several implications for their role. Within publishers a horizontal circulation appears of ecological cycle network diagrams deriving from intra-levelled exam papers, books by the same authors, or other books from the publisher. This circulation may be complemented with examples from higher academic levels. The limited room for manoeuvre when selecting and using references results in ecological cycle network diagrams regularly representing composites of existing references, adjusted according to body text content. The room for manoeuvre is here externally constrained by the nature of the biological content, re-enforced by the curriculum purpose [Section 6.5.1.3, p. 239], and possibly the publisher's budgetary constraints, as also identified in choice point C [section 6.5.3.2, p. 246]:

> '…I was quite happy with the diagram before and there is also pressure from the publishers, if you can use the same diagrams then use them because it saves them quite a bit of money. Obviously, if there is something wrong with it, if I found a mistake or I didn't like it, I would tinker about with it, or if it was a chapter someone else had written and

I didn't like it I would change it. If I was happy with the way it worked before I would keep it.' *#7 UK author*

When re-using or adjusting an existing diagram – brief types a) and b) – the role of the visual reference is to provide the **final-**, or **tentative solution** subject to minor content or visual adjustments. When enclosed with brief types c) and d), the references are used for **inspiration** and **clarification**, rather than a direct reference:

> 'I think it would be rare to find something that looks like something from a different book, literally I mean. Obviously you can't do that, but I don't think that we've wanted to do that. Also, it's been through so many iterations that if it looked like something else to begin with then it wouldn't in the end.' *#11 Danish author.*

With the network diagram and biological information inevitable, these authors are limited to create new composites within the sub-dimension only, *ie*, of the graphic tactics. This limits the level of originality. Several interviewees explicitly commented on the influences of references within this severely constrained room for manoeuvre:

> 'We might send them [the designers] a copied page or the entire book. But it can be a bit risky. Because it can't be a straight copy. It has to be something created originally. It's a truly grey area.'
> *#13 Danish Head of publishing*

All interviewees mentioned copyright considerations within this 'grey area'. All UK editors expressed dissatisfaction about copying diagrams without visual adjustments, resulting in diagrams within a book having different visual styles. Only two editors, however, reflected on the underlying assumptions:

> 'Sometimes you find mistakes repeated in several different textbooks, because we're all referencing each other. It's strange how set ideas develop about how particular things should be described and visualised.'
> *# 14 Danish editor*

> ‘We just sort of assume that they are OK [laughs]. Actually, I don’t think we’ve done enough trialling of saying how actually could it be drawn completely differently. We’ve sort of tended to assume that there’s a way to draw a lot of science diagrams. Particularly technical ones have been used over and over again by the students. The ways they are used in revision books are a good and clear way of showing things.’
> *#5 UK senior editor*

The role of references thereby highlights a crucial underlying assumption about current practice, and the effectiveness of existing diagrams. This reinforces the ecological cycle network diagram as a staple in the ‘design lexicon’ for educational publishing. Such circulation of references underscores the need for precision for each individual graphic tactic when categorising information using graphic syntax. This discussion is expanded in chapter 7. For now the different roles of visual references are summarised in figure 6.25.

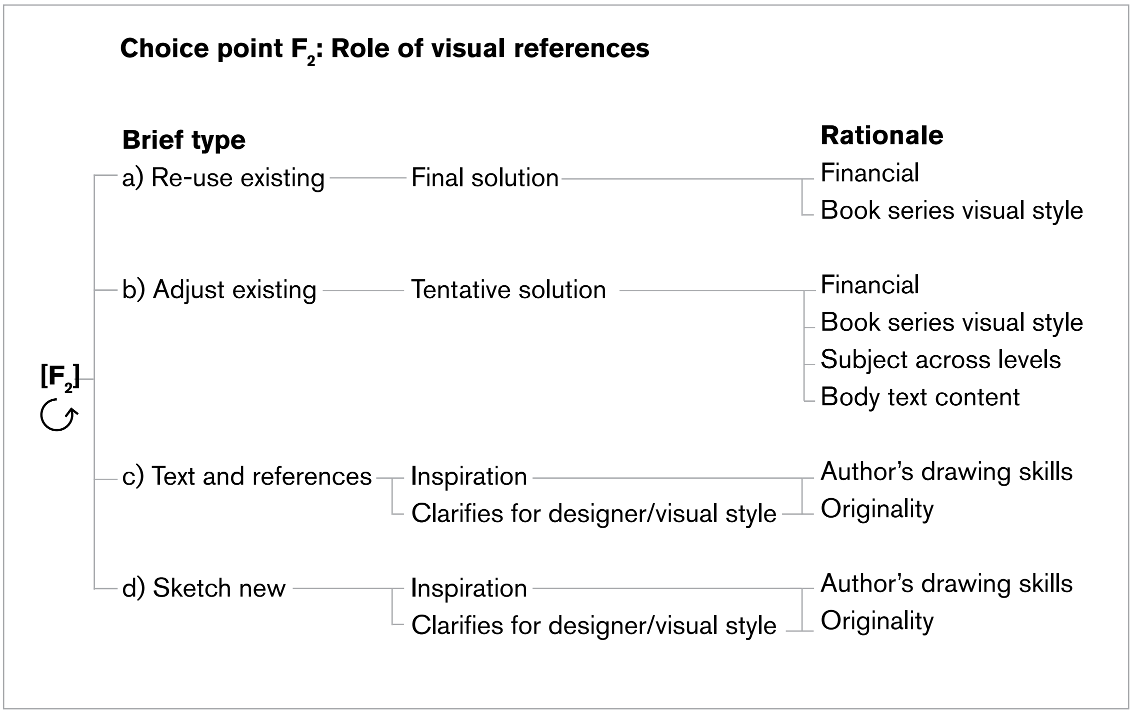


Figure 6.25: Choice point F_2: Roles of visual references

6.5.6.3 Visual references: variation and reasoning

Visual references may be submitted by the author to the editor – depending on brief type – and/or by the editor to the designer. In either case, the decision-making includes the type of reference and its role. The type of reference is led by the inevitable network diagram type, externally constrained by the biological content and curriculum level.

In theory, visual references act as external constraints on the design problem. In practice, when re-using existing diagrams, the references represent the overall solution, except possible adjustments to verbal syntax and visual attributes for brief type b). When either the author or editor are sketching a new diagram visual references are external constraints, informing the brief evaluation or sketching. Here the inevitable types of references result in a problem space so tightly constrained that the visual output mainly represents composites of existing diagrams. In either case, the brief development represents the problem setting process based on the problem-solution co-evolution.

6.5.7 Brief development process

The findings presented for the choice points in the brief development process [A-F] have revealed the features attended to at each choice point, variation in approaches to problem-solution pairings, and the reasoning guiding the decision-making. Combined, these findings form a cross-sectional view of the design situation in relation to the brief development as summarised in figure 6.26 [A3 fold out]. These organising principles now form the basis for analysing how the participants navigate among the choice points and identified features. This process oriented view reveals the problem-solution co-evolution (Dorst and Cross, 2001) during the brief development process, and how decisions at one choice point affects decisions at interrelated choice point. Figures 6.27-30 [A3 fold outs] present the variation in the sequence of choice points found within the data set. The variation in these sequences is dependent on the authors' approaches to specifying the artwork brief, *ie,* brief types a)-d) [Section 6.5.3, p. 244]. These process sequences document the status of decisions for each graphic syntax aspect. This indicates the transfer of 'focus and fitness' within the design process as the problem-solution spaces co-evolve (Dorst and Cross, 2001) and reveals the brief development as the problem setting process.

A3 fold out - FIGURE 6.26:

A3 fold out figures: 6.27-28:
SEQUENCE OF CHOICE POINTS A AND B

A3 fold out Figure 6.29:
SEQUENCE OF CHOICE POINTS C

A3 fold out Figure 6.30:
SEQUENCE OF CHOICE POINTS D

6.5.7.1 Problem-solution co-evolution in brief development process

Figures 6.27-30 summarise when sub-problem and solutions are paired, by whom, and the status of decisions at each choice point, *ie,* how the problem setting has progressed through the brief development process. Figure 6.27 shows how the re-use of an existing diagram results in omission of the other choice points, *ie,* omitting the problem setting process. Brief type b) [figure 6.28] adds considerations of the biological content, possible visual attributes, and includes the existing diagram as a visual reference. However, the problem setting activity is limited. These brief types were only described by UK interviewees and appear to be guided by financial considerations and the tight external constraint posed by the exam specifications.

Brief types c) and d) reflect the inevitable solution of the former brief types, but leave more room for manoeuvre for the editor and author. In these cases the network diagram is inevitable whilst the biological content may be subject to complementary text image relationships. Both of these decisions are constrained by the curriculum purpose. This inevitability of the overall problem space in turn yields a largely inevitable sub-dimension with typographic attributes, and possible colour coding already set. The room for manoeuvre for the remaining sub-problems depends on the brief type.

When submitting text and references [figure 6.29], the author transfers the entire room for manoeuvre for the editor to decide, whereas a diagram sketch [figure 6.30] presents the editor with tentative solutions. The external constraints are here practical teaching and editing experience, visual references, and the underlying curriculum purpose. In one case, the verbal syntax is prescribed by the UK's OCR specifications.

The identified variation in approaches and design constraints were identified in data from both UK and Denmark. Only two differences were found between the two countries: brief types a) and b) occur only in the UK, as does inflexible verbal syntax. Three external constraints appeared as the strongest influence in the problem setting process: the curriculum purpose, the biological nature of the content, and the aim of submitting a clear and detailed brief to the designer, to reduce costs from iterations. The curriculum purpose strongly underpins the rationale for re-cycling or creating composites of existing diagrams. This may contribute to repeating ineffective graphic tactics when referencing other sources. The tightly specified outcome now represents the room for manoeuvre submitted to the designer for translation.

6.6 Translation process

The translation process begins when the editor submits the artwork brief to the book designer or illustrator, and comprises the translation of an artwork brief and any visual references into a final published diagram. This usually happens via email, although some invite the designer/illustrator to a face-to-face meeting to verbally describe details and purpose[7]. Such meetings are more common in Denmark. The translation process here involves two choice points: translation of the brief [G] and evaluation of diagram proof [H].

6.6.1 Choice point G – translate the brief

Brief development process [section 6.5]						Translation process [section 6.6]	
[A] Diagram type	[B] Biological content	[C] Specifying artwork brief	[D] Sketch diagram	[E] Brief evaluation	[F] Visual references	**[G] Translation of brief**	[H] Evaluation of diagram proof
[6.5.1]	[6.5.2]	[6.5.3]	[6.5.4]	6.5.5]	[6.5.6]	[6.6.1]	[6.6.2]

The level of detail in the artwork brief means that the designer receives a design problem of which several sub-problem-solutions pairings are final. The most flexible room for manoeuvre for the designer to engage with comprises decisions about size and container shape visual attributes, pictorial objects, typographic hierarchies – within nodes or arrow labels – respectively, and tweaking the overall spatial organisation within the page layout constraints and biological accuracy [figure 6.31]. This compositional activity represents the translation sub-process.

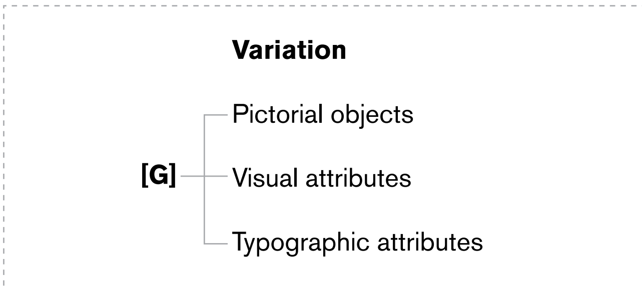


Figure 6.31: Variation at choice point G.

7 These meetings include all the artwork briefs for the given publication.

6.6.1.1 Translation sub-process

The designers/illustrators described their activities according to the brief types. UK designers restricted to adjusting existing diagrams naturally perceive their creative input as limited:

> 'Usually, we very rarely have to put in much artistic input really… we don't really get to say, "Wouldn't it look better like this?", again because of the time constraints. Someone sat and worked out that that would look best and we're not scientific enough to say, "Actually that arrow is facing the wrong way!", or you know sometimes we will say you know, that "You've got the arrows…that the oxidated blood is going the wrong way or something". But usually it's been so fine tuned before we see it that there's very little room for us to change it.' *#9 UK designer*

In contrast to this, both Danish and UK designers/illustrators felt their creative input to more flexible briefs as significant:

> 'As I mentioned, the authors haven't always got a clear vision for how they want it. Then it's my task to say, "When we unfold it like this, then what needs to be included for it to make sense?". It's often the task that I visualise it so they don't have to write a detailed description.' *#17 Danish illustrator*

All designers/illustrators – except one, who was previously a teacher – saw their biology competencies limited:

> 'I don't make suggestions to the message, that would be beyond my competence… Obviously, I'm interested in the subject and try to figure out how, what it actually is, but I don't go looking for alternatives and suggest different ways of doing it. I simply aim to visualise the author's thoughts.' *#12 Danish designer*

The designer/illustrator thereby concentrates on the aesthetics and spatial organisation. This activity yields tentative sub-solutions, subject to the author and editor's evaluation and iteration [H] [section 6.6.2, p. 277]. The room for manoeuvre for aesthetics, *eg,* for pictorial objects, has been indicated by editors and authors quoted throughout this chapter. This ranges from **copying**, '**copy and embellish**' [editor #1, section 6.5.3.4 p. 249] to making a diagram '**exciting**' [author #11, section 6.5.3.5 p. 252]. The most flexible room is here externally constrained by the book series style and the author or editor's preferences, which may be outlined through visual references. This reduces the translation process to three general tasks: create nodes, arrows, and adjust the overall harmony – whilst balancing aesthetic considerations and biological accuracy. All designers/illustrators described their process as detailing and positioning nodes first, before adding the arrows [figure 6.32], working straight on the computer, except one illustrator working in water colour, which is scanned by the publishers.

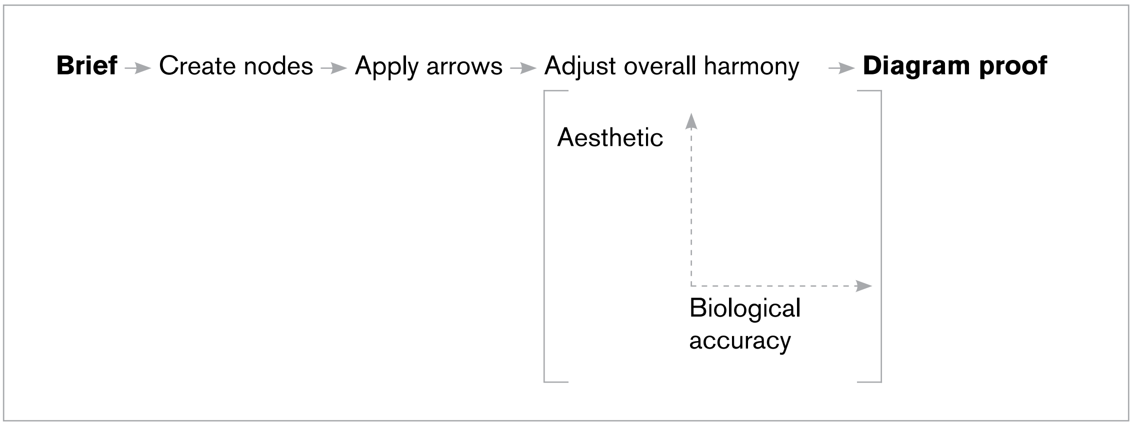


Figure 6.32: Translation sub-process sequence.

6.6.1.2 Pictorial objects

Pictorial objects may be re-used within and across the individual publisher's textbooks; reflecting the general circulation of diagrams:

> 'That factory has almost become a standard within Danish illustration when it's something about pollution. The plants have to be the right ones, the ones that absorb nitrogen, and the animals are chosen because they eat plants, and they aren't bigger than they could fit within the drawing...and that they also fit within the other drawings because that rabbit is in this one as well.' *#17 Danish illustrator*

The re-use of graphic objects appears guided by budgetary constraints, however, some authors also mentioned recognition of a concept, *ie,* positive redundancy, across a publication as a rationale. The room for manoeuvre for pictorial objects reflects that for the aesthetic adjustments outlined above.

6.6.1.3 Visual attributes

Arrows are generally added after positioning the nodes. Their relatively different sizes may be decided in relation to biological accuracy, *ie,* a **concept-to-attribute** relationship (Engelhardt, 2002: 135). The precision here is constrained by the nature of quantities in the cycles:

> 'I'd prefer to have the arrows in realistic scale, but that can't be done in these diagrams because of the differences in flow quantities. So the second best option is relative sizes. The external reviewer commented on the imprecision of the sizes though' *#1 UK designer*

Other designers focus on an **aesthetic object-to-object relation**:

> 'I consider the arrows in relation to the typography, *eg,* their width, the leading, and the font size.' *#12 Danish designer*

These two approaches also apply to balancing the overall aesthetics. In both cases, the designer/illustrator is developing tentative sub-solutions, subject to the evaluation.

6.6.1.4 Typographic attributes

For flexible briefs, some designers mentioned considerations of typographic detailing within nodes or connectors in addition to the sub-solutions set by the book layout:

> 'I consider the line break, and that maybe it's a good idea with upper case for those main groups [of information in a node]. Then I make sure that there aren't any line breaks. That's important for me. And then a form emerges from all those part-decisions. Then I add the arrows. Initially they looked different, and when the author sees it, then he gets those ideas that one should be a chemical energy and one should be oxygen, and in this way it takes shape. It starts by what it has to say. Obviously, you have to start at a place and the shape of this comes from

> how much space is available and how much text has to be included and the background behind the elements.' *#12 Danish designer*

In such cases, the designer is actively categorising the information, developing a tentative sub-solution, subject to the author and editor's evaluation.

6.6.1.5 Translate brief [G]: variation and reasoning

Choice point G involves a sub-process of three stages: create nodes, apply arrows, and adjust harmony in relation to aesthetic preference and biological accuracy. The variation in approaches for each of these is summarised in figure 6.33.

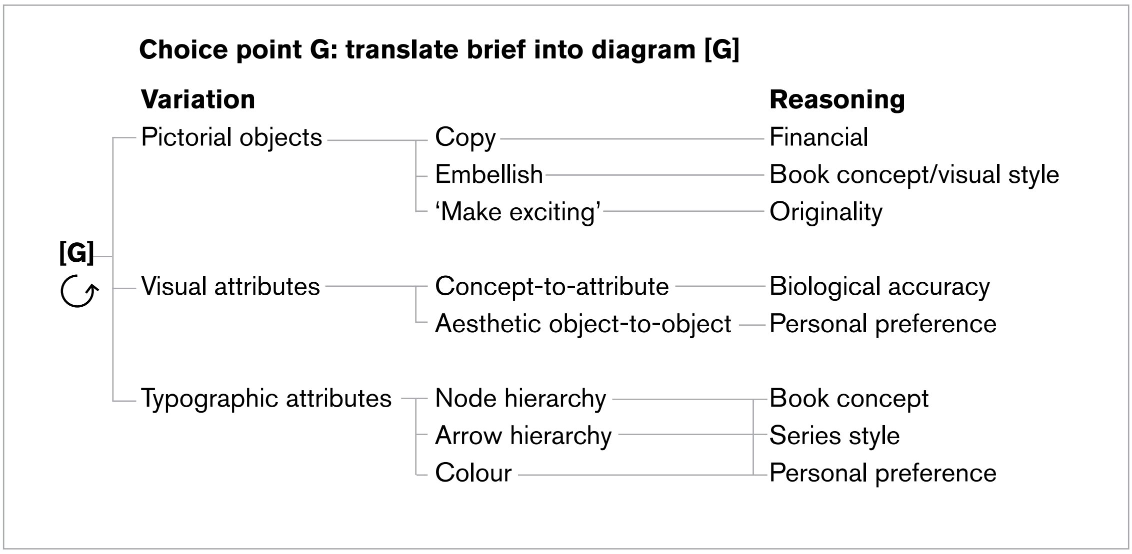
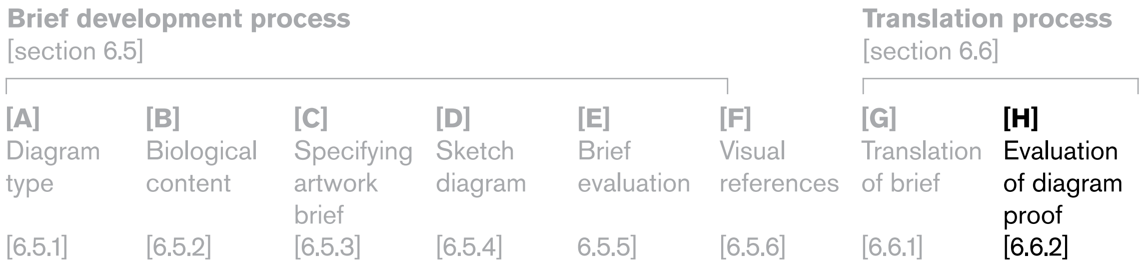


Figure 6.33: Variation in approaches to problem-solution pairing at choice point G.

The decision-making is here hedged by any visual references, brief specifications of visual and typographic attributes, biological accuracy, and personal preference. Personal preference is generally informed by previous professional experience, conventions, and intuition, rather than academic research on graphic syntax. All interviewees demonstrated tacit knowledge about cognitive and physiological benefits of a diagram as identified in choice point A – the general purpose [section 6.5.1.2, p. 238]. Editors and authors stated that they are informed about specific image-related issues only if covered in science educational journals. Direct academic input on graphic syntax appears limited to typography and usability issues, *eg*, font size and legibility. No interviewee stated formal awareness of Gestalt theory or academic journals such as *Information Design journal*. This reveals an asymmetric relationship between the input from academic research on graphic theory, compared to that of learning theory or biology theory. Authors and editors actively update knowledge on teaching and learning theory – through conferences and journals – to inform the book concepts. This asymmetry is discussed further in chapter 7.

The designer/illustrator now submits the diagram proof for evaluation, representing a tentative overall solution.

6.6.2 Translation choice point H – evaluation of diagram proof



The decision at this choice point represents approval of an overall solution, including all sub-solutions. The diagram is usually evaluated as placed within the respective page layout. This results in two overall evaluation focus: the diagram in relation to other page elements, and the diagram as a separate entity (figure 6.34).

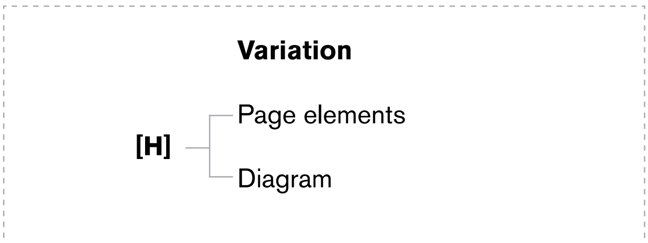


Figure 6.34: General variation at choice point H.

6.6.2.1 Evaluation criteria for page elements

When evaluating the diagram as a page element, the focus is on the general **visual harmony,** but also the text image relationship, *ie,* the

complementation or **supplementation**:

> 'I'm never just looking at the diagrams. What I look at when I get the proofs is the whole thing: does it work, does the whole thing work, does the spread work? so I'll be reading the text and the diagrams to make sure that they actually fit together.' *#1 UK author*

The evaluation criteria for the individual diagram vary depending on the level of flexibility left by the brief. Diagrams based on detailed sketches, *ie,* inflexible briefs, are checked against the artwork brief, for **spelling mistakes, arrow size**, and/or **arrow positioning** only:

> 'Does it resemble what the brief asked for, is it correct, does it convey the information without errors, does it follow the guidelines, is the size right? I don't review the actual content included because we're committed to the artwork brief at that point.' *#2 UK Senior editor*

For diagrams based on flexible briefs, this basic proof reading is expanded with further evaluation criteria: the **number of objects, biological accuracy** and **visual harmony**:

> 'We look at whether it tells the story we want it to. Does it give an impression of the subject? And then we look at the biological accuracy. That's actually the first. It can't be biological incorrect, it has to be comprehensive, all the thoughts included, but it can't be wrong. We also want it to look good, there has to be visual harmony.' *#11 Danish author*

This reflects the consideration identified for specifying and evaluating the brief [C and E], [figure 6.26, p. 266]. Biological accuracy was mentioned repeatedly by editors and authors:

> 'It has to be biological accurate for the specific level…what you learn at GCSE biology is not necessary correct for what you learn at A-level. But you are also very much influenced by what examiners are asking for when students are answering questions, and you know that if they are expected to know about nitrifying bacteria and decay bacteria then that's got to be on your diagram and in the right place. Whereas in

other specifications they don't need to learn that so you can go straight through and miss that bit out. So you're very heavily influenced by that. *#2 UK author*

6.6.2.2 Evaluation of diagram proof [H]: variation

The diagram proof evaluation criteria are summarised in figure 6.35.

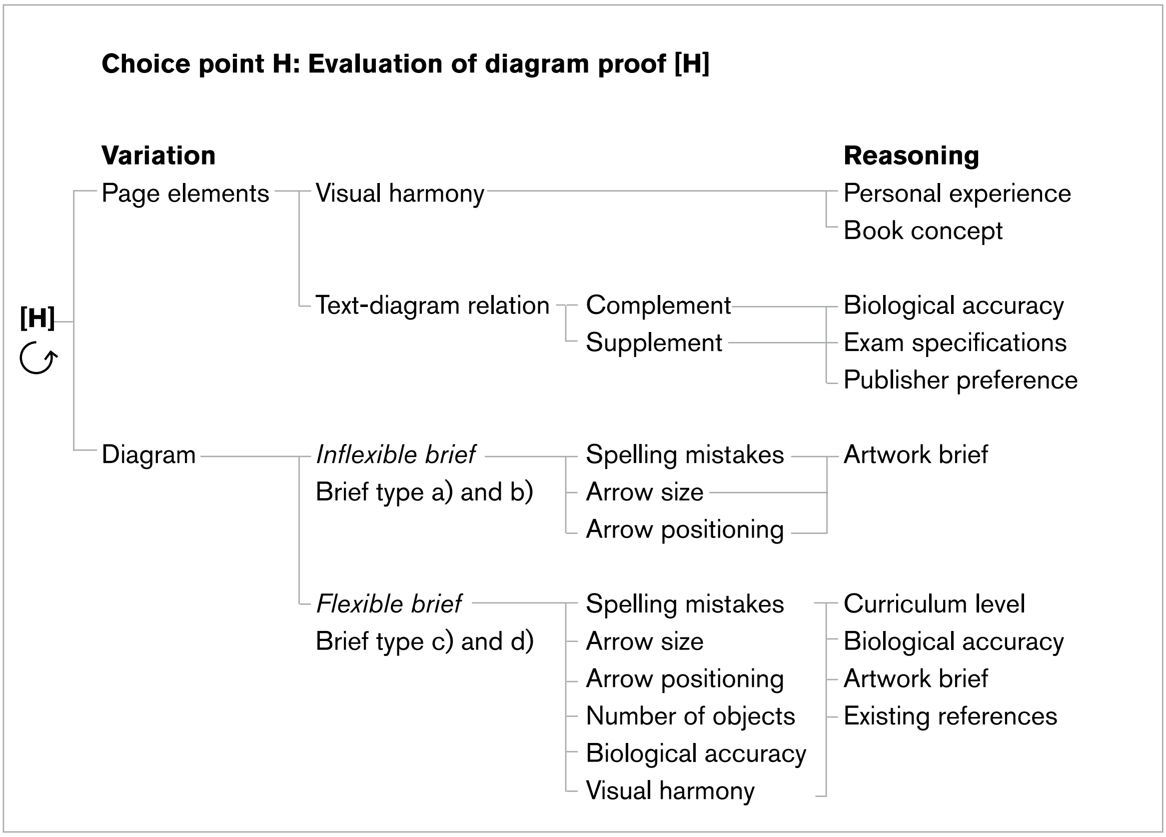


Figure 6.34: Variation in approaches at choice point G.

The main external constraints influencing the evaluation of diagram proofs are the general purposes of visuals and curriculum purpose [A] [section 6.5.1, p. 236], the brief evaluation criteria [E] [section 6.5.5, p. 256], and the artwork brief itself. The evaluation of flexible briefs may lead to iterations and reconsidering different tentative sub-solutions. This in turn affects the sequence of choice points in the overall transformation process.

6.6.2.3 Flexible briefs: iteration

The output from translating a flexible brief represents a tentative overall solution, subject to convergent or divergent iteration. Convergent iteration mainly concerns mistakes in the linkage of biological concepts within the diagram. Some editors mentioned different sources for such mistakes: omissions by the author or editor, mistakes in the brief, or mistakes in the designer's translation. However, all authors and editors stressed that mistakes in the designer's translation were particularly common:

> 'The designer doesn't have a biology background, we definitely notice that. Sometimes the arrows are positioned quite randomly. Then we correct and have often sent the diagram back and forth with arrow corrections.' *#16 Danish author*

Divergent iteration resembles a visual dialogue between author/editor and designer/illustrator. Even within the limited room for manoeuvre, the unfolding of the author's thoughts may be a catalyst for some further development, centred around visual deepening, *ie,* adding visual attributes to arrows to create sub-categories of information, or biologically broadening – adding biological concepts. The considerations here reflect those identified when selecting biological content [B] [section 6.5.2, p. 240] and specifying the brief [C] [section 6.5.3, p. 244]. Interviewed authors expressed particular focus on arrow meanings and the effect on a diagram's complexity during these iterations. Where some authors perceive this type of iteration as a learning curve, for others it is a cause of irritation:

> 'This figure has too many arrows. It's too complex…it ends up being some boxes and some arrows. But what is it actually that those arrows do? One thing is that they understand that those arrows are a connection, or an effect, but what is actually present in such an arrow? A process, or is it one that pushes another one, or what is it actually? I learned a lot from the arrows in my previous book. I learned that I had to be more precise with differentiating when something is matter and when it's a process. I found it was an advantage that the designer isn't a biologist, because then they've got the same circumstance as our pupils.' *#15 Danish author*

> 'The difficulty is that the majority of artists aren't scientists and they are not biologists, so they don't understand what the important features of whatever it is that you want them to draw and you may not…it's

difficult for me to have the insight into what they will realise and what they won't realise. So I can send something off that to me is absolutely obvious, and then I'll get something weird back.…you can get a lot of toing and froing and you end up with a thing you really don't like.' *#1 UK author*

The participant relational aspects of these statements are discussed in section 6.7.3, [p. 292]. Seen in the light of the visual content analysis findings from this research enquiry, it is interesting to find that the authors have particular focus on the arrows. Indeed, most participants were critical of their own diagrams during the interviews, and often found mistakes with arrows, during our conversation:

> 'We spent a lot of time on the arrows, because there are so many arrows in different books that don't work. And I'm sure there are arrows in this series that don't work. I've just noticed that there are arrows missing from the underground streams into the well…' *#16 Danish author*

> 'I think, really, if you look at this, if I was drawing this again, you would have feeding process, then excretion, or death – that should really be by that arrow because it's more of a process, then you get to organic remains… If I had proof read this more carefully, I would have changed this to one arrow with decomposition. The problem is of course that decomposers are there but decomposition is not – I would have thought it fussy but they might have said, "you can't use the word decomposition you have to use the word decomposes".' *#7 UK author*

This awareness of detailing arrow meanings similarly came to light when the interviewees were asked to evaluate the Spanish diagram example shown at the end of each interview [section 3.3.3.1 p. 85; appendix 1]. All participants identified ineffective graphic tactics, *eg,* illogical linking sequences or imprecise nodes. Thus it appears that authors and editors in particular, but also designers, are aware of such ambiguities both in their own and other publications. The split evaluation focus – reviewing the diagram in relation to the page layout, as well as the individual diagram – may contribute to the presence of ambiguities, as may the time available for evaluation. For authors who are actively teaching or examining, this poses a significant external constraint:

> 'There was an enormous pressure on getting those books out. And some things just had to go through. You're sitting on a Saturday or Sunday evening and you have to get up to teach. And then some email arrives late at eleven PM and there's a deadline the following day. Then it's not "is the perspective OK in this drawing?" Then it's "OK, does it work, are there any spelling mistakes, are the arrows linked OK?".'
> *#16 Danish author*

An underlying trust in an existing reference may also be a feature which influences the evaluation:

> 'I am normally quite strict about what an arrow means, I say "normally", because we've been picked up a few times by our reviewers on this, but don't forget I'm using, I'm inheriting, some old diagrams that I'm redoing.' *#1 UK designer*

The continued presence of ambiguities may also be affected by schools' budgetary constraints. Spelling mistakes may be corrected in second editions of the books, however, editors in both countries explained that schools use both first and second editions together. This prevents bigger alterations of diagram content until developing a new publication.

The nature of divergent iteration reveals several interrelations between choice points in the translation process and brief development process. These may be illustrated by organising the choice points in the overall information transformation process sequence.

6.6.3 Information transformation process sequence

The identified features that are attended to at the two choice points in the translation process, the variation in approaches to problem-solution pairings at each point, and the reasoning guiding the decision-making are summarised in figure 6.36 and 6.37 [next page]. These organising principles enable a process oriented view of the translation process combined with the brief development, *ie,* the information transformation process. Figures 6.38-6.41 present the variation in sequences of all eight choice points in relation to the brief type and different types of iteration. These process sequences reveal the movement in the participants' focus during the information transformation process, the delegation of responsibilities, and the transfer of 'fitness' between choice points in the form of final sub-solutions, tentative sub-solutions, or transferred sub-problems. This demonstrates the problem-solution co-evolution during the translation process and the overall information transformation process.

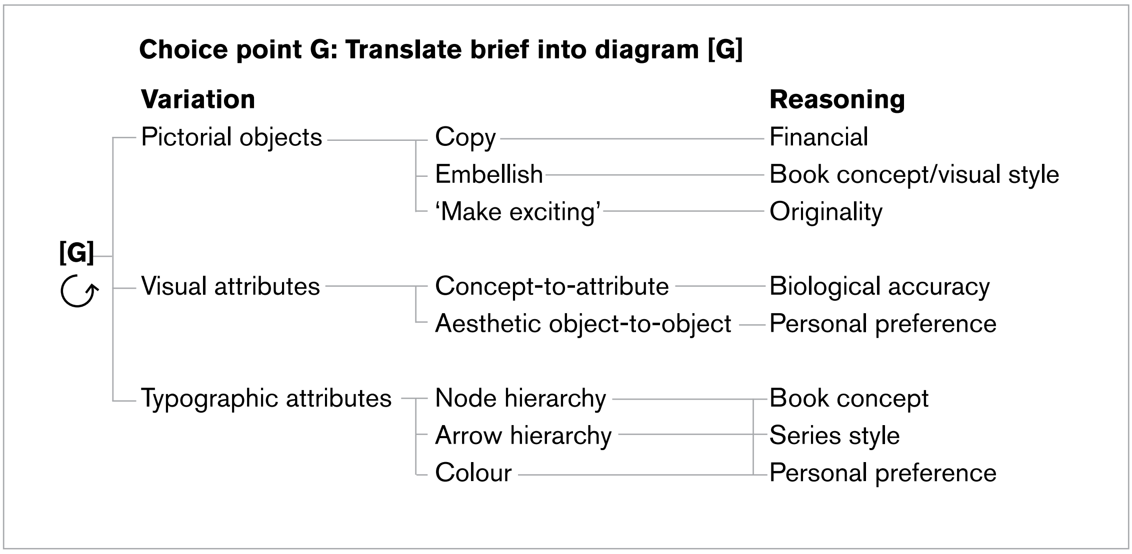


Figure 6.36: Variation in approaches to problem-solution pairing at choice point G

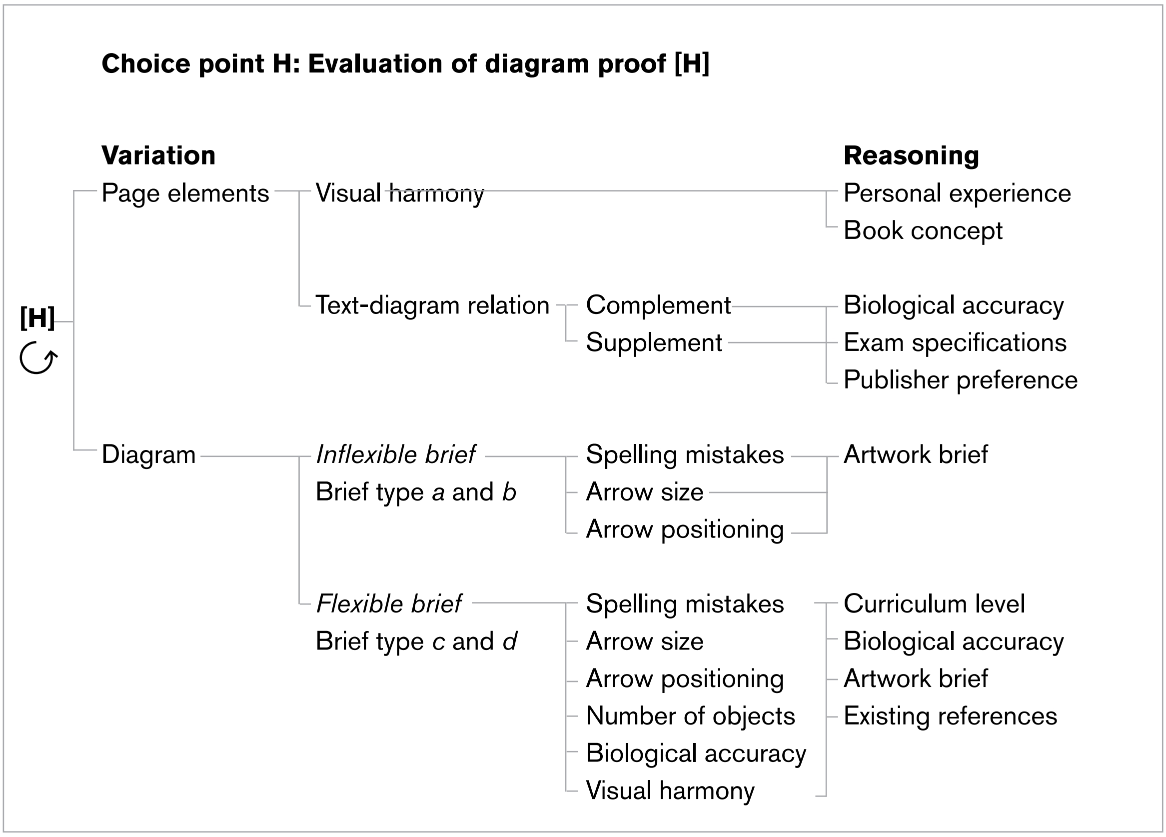


Figure 6.37: Variation in approaches to problem-solution pairing at choice point G.

A3 fold out Figure s6.38 AND 6.39 BRIEF TYPE A AND B

A3 fold out Figure 6.40
BRIEF TYPE C

A3 fold out Figure 6.41
BRIEF TYPE D

6.6.3.1 Problem-solution co-evolution in information transformation

The translation process reflects the findings, that the majority of the design problem is set by the author and editor in the brief development process before reaching the designer or illustrator [section 6.5.7, p. 265]. The room for manoeuvre for the translation depends on the flexibility of the brief. When adjusting existing diagrams, the translation is omitted or reduced to simply adjusting terminology or aesthetics [Figures 6.38 and 6.39]. Flexible briefs allow for deciding on sub-problem-solution pairing for the visual attributes, pictorial objects, typographic hierarchies in nodes and arrow labels, and adjusting the spatial organisation within the given space.

The translation is primarily informed by personal preference, and tacit knowledge – rather than formalised graphic theory – and hedged by the brief specifications and visual references. This also informs the evaluation of the diagram. The evaluation of flexible briefs [Figures 6.40 and 6.41] may result in divergent iteration processes, in which the biological content is broadened or visually deepened [B] – within the direct and tight feed of constraints from the overall problem space. Divergent iteration processes were seen only in the Danish transformation processes, in response to flexible briefs, and with the author-design team in the UK. The identified sequences of problem-solution co-evolution are interesting seen in relation to existing discussions of whether the problem and solution spaces co-evolve through bridging or through a 'creative leap' (Dorst and Cross, 2001; Cross, 2000; Archer, 1964/1984). In this context, the UK-derived inflexible briefs require no leap, or even creativity. The problem is the solution. Sketching a new diagram and translating the sketch involves minor bridging in divergent iteration processes.

Significantly for the focus in this thesis, the interviewees demonstrated awareness of ambiguities resulting from included ineffective graphic tactics. Their suggestions that the dual evaluation focus – the diagram and its relation to other page elements – time pressure, or that the close reference of existing diagrams may influence these occurrences, represent significant features in the situational context which may affect the current information transformation rationale.

6.7 Current information transformation rationale

The estimated time frames and participant relations within a design situation are features which may affect the decision-making at any individual choice point and the interrelations between choice points. These additional analytical insights enable a discussion of the current information transformation rationale in relation to 'reflective conversations' (Schön, 2006).

6.7.1 Situational context

The first analytical perspective of the design situation has enabled a cross-sectional view of the design situation, to identify features in the situational context which may affect the decision-making in the information transformation process. These external constraints are summarised in figure 6.42, next page.

Design situation

Situational context/external constraints

Visual variation [A]
Cognitive effects [A]
Dual processing [A]
Cycle type [A] [B]
Making spatial relations clear [A]
Exam specifications [A] [B] [E] [H]
Publisher preference [B] [E] [H]
Curriculum level [E]
Financial [C] [F] [G]
Book series visual style [C] [F] [G]
Subject across levels [C] [F]
Body text content [C] [F]
Author's drawing skills [C] [F]
Originality [C] [F] [G]
Biological accuracy [D] [G] [H]
Teaching experience [D]
Intuition [D]
Reading level [D]
Personal experience [E] [H]
Book concept/visual style [G]
Personal preference [G]
Book concept [G] [H]
Time [G] [H]
Artwork brief [H]
Existing references [H]

Design problem/ internal constraints
Categorising six information types using six graphic aspects whilst reducing implicit nodes, imprecise nodes, polysemy, and inconsistency [figure 4.51]

Figure 6.42: Features in the situational context which may affect the design decisions.

The analysis has revealed an overall problem space tightly constrained by the curriculum purpose and biological nature of the ecological cycle subjects – in both Denmark and the UK. This results in an inevitable overall solution, with only some instances of flexible solution options (Archer, 1964/84) in the sub-dimension: complementary body text-diagram relationships [section 6.5.1.1, p. 237], verbal syntax, visual attributes, and use of pictorial objects, all hedged by the publisher's preference [section 6.5.7, p. 265].

The main difference between UK and Denmark is the tighter level of constraints posed by UK exam specifications, which affect the synopsis stage, re-use of existing diagrams, sub-problem-solution pairings such as verbal syntax, and the resulting development of inflexible briefs [section 6.5.7, p. 265]. The inevitable overall solution in both countries results in the design situation dominated by solution constraints, *ie,* focused on the solution rather than the problem. The external constraints were identified as part of the organising principles for individual choice points. However, two features influence the decision-making at all choice points, as well as their interrelations: the time available – highlighted at choice points G and H – and the additional feature of the participant relations.

6.7.2 Estimated time frames

The amount of time available for each sub-problem-solution pairing varies depending on the individual process, reflecting the organic nature of the publishing process. The nature of the data set here allows for identifying estimated time frames of different information transformation activities. Danish books are generally in print for up to 10 years, while UK books are limited to five years. These features are directly linked to the life span of curriculum updates. The differences in time available for the overall process and editorial stage in the two countries relate to the level of structure prescribed by the respective exam specifications [section 6.4, p. 233]. One example is the development of an entire Danish series, for three year levels, which allowed two-three years for developing and adjusting the concept through the first publication, and an additional two years for each individual book. Compared to this, the UK process is severely tightened. An A-level book process may start in March and the book launch in January, *ie,* ten months. Within this time span, an experienced author may complete the manuscript and artwork briefs in three months. For translation, designers in both countries estimate around four to five hours for flexible briefs, UK designers one to two hours for inflexible briefs [table 6.7, next page].

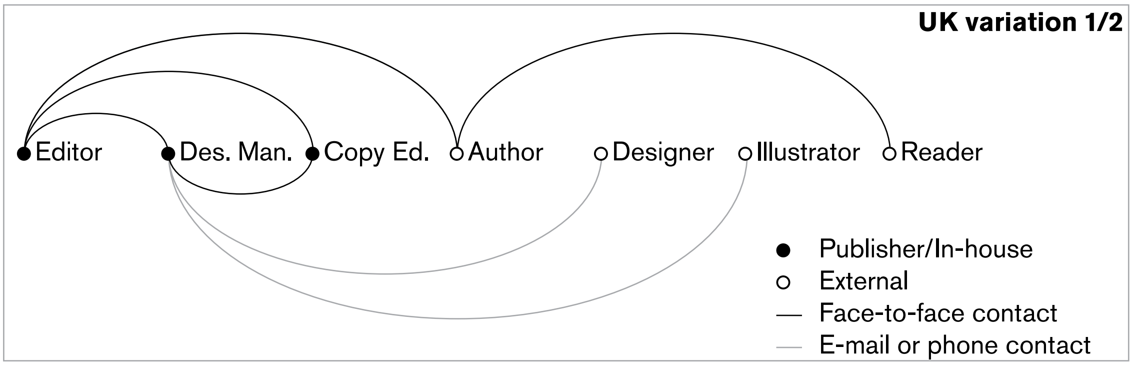
Time factor	Estimated time available
Life span of book	UK: 5 years DK: 10 years
Overall book process time	UK: 10 months DK: 2 years
Editorial stage: manuscript and artwork briefs	UK: 3-4 months DK: One year
Translation of brief (excluding iterations)	Inflexible brief: 1-2 hours Flexible brief: 4-5 hours
Evaluation of proofs including diagrams	UK: 2 weeks DK: Not identified.

Table 6.7: Estimated time available for tasks, as identified in the data set.

Several human factors add to the organic nature of the time estimates. The authors' teaching or examiner schedule affect the continuity, with work often scheduled around holidays, weekends, and evenings. Designers and illustrators may also be working on simultaneous projects. Some in-house participants work part time and on several other projects at a time – one UK design department had 756 components in development at the time of interview. This results in different parts of a book, possibly from different authors, often progressing through the general publishing process stages in fragmented and individual paces, including the evaluation points. This is particularly common in the UK, enabled by the level of pre-specified content strcutures. These estimates indicate an organic network of time-related constraints which affects both the brief development and translation process. Adding to the organic nature of the process, are the links in participant communication.

6.7.3 Participant relations

Several variations in communication links, *ie,* face-to-face contact between participants were found in the data set. Four different constellations here emerged between author, editor, designer, illustrator, and the reader groups of teachers and pupils. These relations are presented visually [figures 6.43-46, page 294], informed by Zeisel (1988), Lawson (2006), and Crilly (2005). The identified nuances in the communication links between participants, enable further analysis of the formal and informal delegation of responsibilities within the analysed processes. The identified participant relations are essential for later identifying the models of design activities and integrating the findings from the two *research strands*. Figures 6.42 and 6.43 represent the participant relations found at UK publishers and include copy editor and design manager/production manager. Commissioning editors are excluded from these diagrams, as they operate at a general level with no direct involvement in the individual diagram design.



Figures 6.43: Communication links between participants. UK variation 1/2

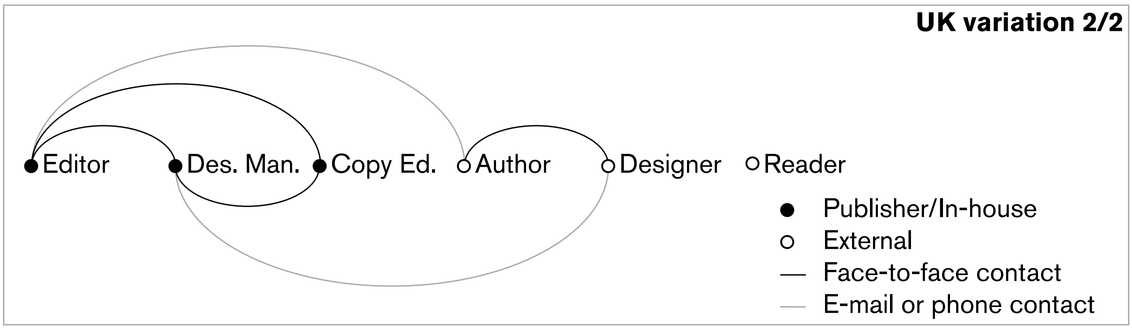


Figure 6.44: Communication links between participants. UK variation 2/2

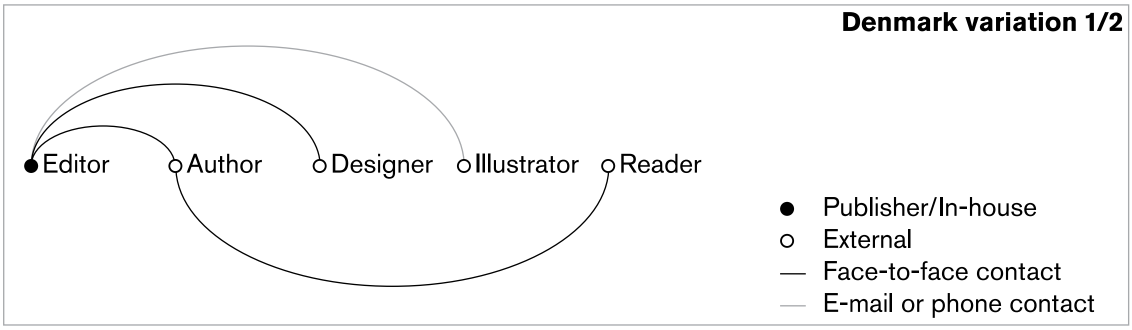


Figure 6.45: Communication links between participants. Denmark variation 1/2

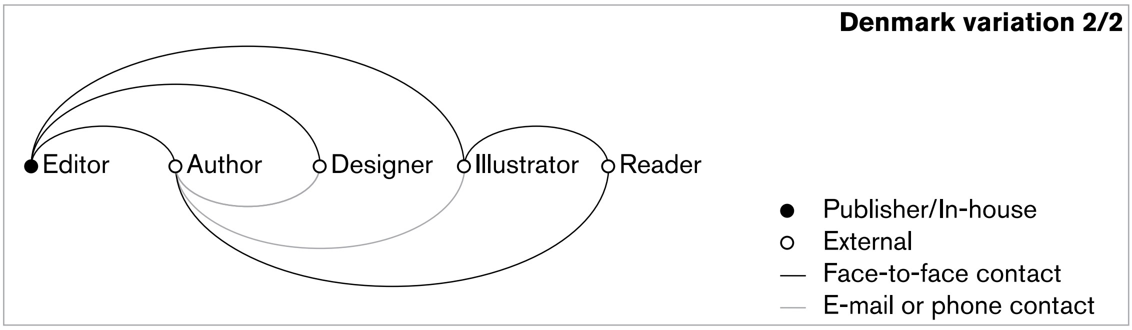


Figure 6.46: Communication links between participants. Denmark variation 2/2

6.7.3.1 Communication links between editorial team and authors

The UK editorial teams and authors may meet in the beginning of the editorial process. With experienced authors or authors of one chapter only, the author may instead be briefed by email. Throughout the brief development authors and editors are in contact – by phone or email – only if the evaluation yields significant changes. In-house editorial teams meet informally and formally face-to-face throughout the general transformation process. They do, however, not meet to discuss individual diagrams. The difference in the synopsis process between Denmark and the UK [section 6.4 p. 233], affects two aspects of the Danish participant relations. Firstly, it tightens the co-author relations, the teams regularly meeting face-to-face. Secondly, it tightens the relation to the editor, who often has a high level of engagement in the brief development, due to the more flexible nature of the artwork briefs in this country. As mentioned by the author #11 [section 6.5.4.3, p. 249], co-authors may include iterative evaluations of the artwork briefs before submitting to the editor by email.

6.7.3.2 Communication links to the designer/illustrator

In the UK, the design/production manager is responsible for briefing and contact with designers. Within the diagram specific focus, this contact happens by mail and phone only. Face-to-face meetings may happen, however, when briefing the actual book design. This contrasts with Denmark where the book/diagram designer meets with the editor, and often the author. The Danish editor-designer relationships, within the data set, are strengthened by coincidental geographic closeness. The participants may here meet to discuss visual developments if needed. With the exception of one unique designer-author relationship, designers and authors rarely meet face-to-face, in either country. In Denmark one author was in direct phone and mail contact with the designer and illustrator, due to extended detail in the diagrams. Illustrators and designers meet only if they are part of the same in-house department or external company.

6.7.3.3 Communication links to pupil and teacher readers groups

Authors provide the main link to pupil and teacher reader groups through their practical teaching experience. In some cases this provides opportunities to try diagrams in lessons. Some UK authors work as chief examiners and authors only. This limits the direct contact with the readers. However, the examiner work may contribute valuable insights to pupils' difficulties with exam questions in relation to particular aspects or concepts. Commissioning editors mentioned user focus groups as part of the market research, this centred mainly around the book concept and 'look and feel' of the sample design. The diagrams used for this are referenced from previous publications.

6.7.3.4 Nature of communication links between participants

The participant relations highlighted in figures 6.43-47 are organic in nature, as are the factors influencing them. These range from geographic location, personal relations – several interviewees mentioned personal fall-outs between individuals – general logistics, *eg,* teaching schedules, long-term illness – leading to replacements, completing one chapter before others, and in one case two participants being married. This organic nature led some interviewees to describe the participant settings as 'patchworks' or 'Chinese whispers'.

Editors here provide a significant link between authors and designer/illustrators, working as a filter on the artwork brief before the translation. Most authors accepted the indirect link between themselves and designers/illustrators, partly due to financial concerns:

> 'It's a question of finances. If I'm sitting with a graphic designer, then every time the designer has to re-draw something, it adds to the costs. And I can't just say, "that's OK, just do that then". There has to be someone from the publisher to control the costs. Obviously, there is a banal legal matter in what messages goes back and forth, and what I can and cannot expect from the graphic designer. I don't think I'd let a designer and author get together outside the publisher myself, because as author I'm not considering the finance, I just want it to be perfect, and that would cost a lot of money.' *#15 Danish author.*

Some designers also preferred the mediated link to authors for personal or creative reasons:

> 'We have one [author] that comes in sometimes…it takes an awful lot of time because he doesn't understand that sometimes if you're drawing something it can take a lot longer than you think to just draw something, that you think would be quite fast. And he gets really impatient, because you're moving something across the screen.' *#9 UK illustrator.*

> 'I quite like to keep my distance. You can easily be forced in a particular direction if you're more involved. I'm more free to contribute surprising inputs when I don't know all the work that has gone before.' *#17 Danish illustrator.*

The one author, within the data set, who works closely with a designer, prefers the direct link:

> 'Nothing very much happens [with external designers]. You're not really involved, you send off your text and illustration briefs and you get artwork back which you then comment on and hope that they'll get it right next time. And then you'll get proofs and you might get two sets of proofs which you mark up and that's about it, really...[When they work together] I can say, "Would it work if we did this?" And we can actually try it and see if it does...Both of us from the word 'go' are thinking about what it is actually going to look like. We're thinking about what this page is going to look like, we're thinking about 'this is going to be a big photograph and underneath it a diagram'. I've got that in mind even when I'm writing. So I'm thinking a little bit more visually, but not in detail, I've got a rough idea.' *#1 UK author*

Apart from the one case of a direct author-designer link, the general participant relations demonstrate only indirect links between the biological content expertise and graphic knowledge in the transformation process. Parallel with this indirect communication link runs a cultural gap, appearing to revolve around a classic form-content divide.

6.7.3.5 Cultural gaps

In this thesis, cultural gaps relate to different perspectives of participants (Zeisel, 1988: 35) deriving from different subject specialism. Small cultural gaps may occur due to different focus and responsibilities. For example, an author's aim of perfect authorial craft versus the editor's budgetary responsibility [author #15 p. 296]. This type of cultural gap appears to be bridged without major problems within the participant relations found in the data set. One editor mentioned a similar value-conflict with the production department – the production department representing budgetary concerns when choosing, *eg,* illustrators – resulting in the senior editor commissioning the outside designers. In addition to these gaps, the predominant cultural gap within the data set is one between designers and authors. This gap is significant for this thesis, firstly, because it relates to the identified asymmetrical relationship in input on learning theory, biological content, and graphic expertise; secondly, because this cultural gap appeared explicitly in all interviews. This cultural gap is rooted in the authors' role as subject specialists, leading to a content-authority. This authority is acknowledged by all editors, and the authors themselves:

> 'On a practical level, I've got a close relationship with the authors…and in the co-operation with the authors, I see myself as a sparring partner, so, if they're stuck, I make suggestions…but the authors obviously have to agree completely on the biological content.' *#14 Danish editor*

> 'The editor's quite important, actually. I've had editors I have worked with that have been quite good and others have been quite difficult really. You want constructive comments but often they're not subject specialists, and you know, they may try and criticise your biology.' *#7 UK author*

The author's authority usually extends to the visual side of the publication:

> 'The editor is in charge of what the book looks like but the authors have a very strong say in what the artwork should be like. Partly because we want the authors to be happy, we want them to write for us again, and we want to make sure that it's what they want, because the publisher has

> the picture of the book and the market, the author has a picture of the teaching and…in theory knows the audience and knows what they [the pupils] are going to understand. They also know, "This diagram should show these things, and ideally they would say, "This should say this thing in this way".' *#2 UK editor*

The author's science authority affects the author-designer relation. This is evident from designers commenting on their role as visualising the author's thoughts only [*#17*, section 6.6.1.1, p. 273], and authors mentioning misplaced arrows due to a designer's assumed lack of biological knowledge [*16x*, section 6.6.2.2, p. 279. The nature of the brief development as setting the problem and the limited room for manoeuvre presented to the designer – focused mainly on the aesthetics – reinforces this authority. Although authors are critical of designers they do also recognise the positive input a designer can contribute during the iteration process. This was mentioned by the authors working directly with the designers and those seeing their thoughts unfolded during iterations:

> 'I found that in a lot of the things he drew, he added an extra quality which I could use to develop the figures further…I mean, he didn't know a thing about chemistry and all that, and that meant a lot of mistakes…' *#15 Danish author*

Several authors similarly admitted their own shortcomings in relation to knowledge about the visuals, *eg:*

> 'It is so obvious that I lack terminology for discussing the visuals.' *#16 Danish author*

Three participants within the data set bridge this content-form gap, through their extended skills set: an author with strong visual skills, the head of publishing at a small publisher with a background in art history, and a designer who previously worked as a teacher and author, then progressed to the visual side of the publications. The formal graphic design skills here mainly includes visual software skills, *eg,* Adobe Creative Suite, and overall knowledge about the purpose of images, *ie,* the general purpose. Graphic syntax knowledge remains informed at the tacit level only, through their professional experience, and adherence to conventions, *ie,* referencing existing diagrams. The content-form gap was only found to be bridging from the author domain. No participant in the data set had a background in formal design education supplemented with formal biology knowledge.

The cultural gap between authors and designers re-enforces the apparent divide between biological and graphic expertise created through the nature of brief development and translation activities; and the imbalance in input on graphic theory, compared to pedagogical and biological theory. All interviewees stated awareness of these gaps. Where some participants accept, and possibly prefer, the present communication links and cultural gaps – and the general content-form divide, others stated a wish to address this aspect of current practice, providing several suggestions.

6.7.4 Suggestions from interviewees

At the end of each conducted interview, the interviewees were asked to reflect on the positive and negative aspects of their practice and anything they would like to change. This yielded several additional insights. Although explicitly aware about ambiguities occurring, authors and editors are generally satisfied with their visual output. Feedback they receive from teachers appears to generally confirm this view:

> 'We've gotten a lot of feedback from teachers about our series, and there has never been any complaints about not being able to interpret the diagram. I meet a lot of teachers as an examiner, when we do seminars on exams, and we usually end up talking about the books and how they work.' *#16 Danish author*

With this in mind, several interviewees suggested improvements, revolving around budget constraints, the communication links, and cultural gaps.

6.7.4.1 Budgetary constraints

'More time with higher budgets' was a reoccurring issue in the reflections. However, the aim with more time varied. Designers and illustrators wished to attend to their craft in more detail:

'If you were to do this with lots of time, you could do a really nice three dimensional cow and you could do a really nice bunch of flowers…and you know, you could really put more into that…but it doesn't warrant it really…but if it was going on a poster or book cover…you know, it would be nice sometimes to just spend a little more time.'
#9 UK illustrator

On the editorial side, in general, more time would be used on the design concept, *ie,* at the synopsis stage, and more money spent on ensuring consistent aesthetics in re-used and adjusted diagrams across a publication. Some editors also wished to address the authors' science authority in relation to the visuals:

'Yeah, I think it works [the current process] but talking to you [laughs], now, I think I'd actually like to spend more time looking at the illustrations, separately, to actually focus on them more. Because I think, we rely on our authors, I mean, they are often teachers and experts, but perhaps there is room there for discussion about the point of the piece of artwork…I mean, we don't have much time once things actually start going and we've passed it. When we've actually got the text in and we're going, there's not much time to suddenly say, "No you need to go away an re-do it". So it would be more in the structure editing of it.'
#5 UK Senior editor

6.7.4.2 Communication in editorial team

Several other interviewees suggested stronger and direct links between the editorial participants to ensure a more integrated overview in the process:

Interviewee 1:
'I would like someone who had a complete overview of the whole thing, prepared to listen, didn't just brush your suggestions under the carpet.
Interviewee 2:
…'Who knows the impact of what is being suggested here on another part of the process, it's a connection between production, design, marketing.'
Interviewee 1:

… 'A problem that we have is that each person has their own little thing that they are responsible for, and we rather lacked the idea. Because the way we work, we're looking at lots of different aspects of… I've even been involved in marketing…we've got an overview and it is actually quite difficult for us to chop the thing up to little bits that suits them'.
UK Author and designer

6.7.4.3 Biology-graphic expertise gap

Other editorial members focused on the biology-graphic expertise gap:

'A cheeky answer to improvements is that I'd like to find a person who's got both left and right intelligence, who's both a scientist and an artist. But they don't exist. But that's the problem actually.'
#13 Danish head of publishing.

A suggested solution to this issue was the integration of a designer in the brief development:

'…As a consultant. That would be a really good idea from the publisher, someone who could ask all those questions and say, "Where is it that this diagram complements the body text, how does it address the pupils' everyday conceptions, what arrows are the central elements, and which ones needs to be deleted?". That would be good. Because it would enable us to conceptualise something we haven't researched.'
#16 Danish author.

Rather than a consultant, one editor suggested an additional role within the editorial team:

'What we need, really, is a visual editor who goes through and checks the detail of all these diagrams. That's lacking from the current set up.'
Comment from pilot interview 1 – UK editor.

In chapter 7 these suggestions for alternative practice are developed as part of the recommendations contributed by this thesis. For now they conclude the overview of the situational context as identified through this research enquiry. The identified design situation in turn enables a discussion of the information transformation process in relation to 'reflective conversations' (Schön, 2006).

6.7.5 Information transformation rationale and 'reflective conversations'

The situational context, as identified in this research enquiry, has revealed several features – in the professional practice context – which may affect the decision-making when generating an ecological cycle network diagram. The tight level of external constraint here reduces the extent to which the identified information transformation processes represent instances of a 'reflective conversation' (Schön, 2006). In the case of re-using an existing diagram, the conversation is limited to evaluation only. Meanwhile, 'reflection-in-action' (Schön, 2006) is evident in the author's sketching of a new diagram [section 6.5.4, p. 253] and in the designer's typographic considerations [section 6.6.1·3, p. 275]. However, 'knowing-in-action' (Schön, 2006) appears to dominate the current rationale, informed by the teaching experience of authors and some editors, experience with previous publications, and designers/illustrator's professional practical experience. This reliance on tacit knowledge fits with the inevitable overall solution, and the apparent underlying assumptions about the network diagram's effectiveness [section 6.5.6.2, p. 262]. Significantly, the reliance on 'knowing-in-action' results, among other things, in the reoccurring practice of creating composites of existing diagrams [section 6.5.6.2, p. 262].

Interestingly, some spontaneous 'reflection-on-practice' (Schön, 2006) occurred during the interviews, with all interviewees discovering instances of, or stating general awareness about, ambiguities in their own diagrams, *eg,* arrow meanings [section 6.5.6.2, p. 262]. This implies, that given the opportunity to reflect on their practice, their tacit knowledge includes awareness of some of the ineffective graphic tactics found in this thesis' visual content analysis [table 5.1, p. 203]. However, the current rationale reveals a general asymmetrical relationship between formal 'reflection-on-practice' focused on the biological and that focused on the visual content. This is evident in the level of theoretical input on the pedagogical and biological aspects of the text books, compared to the low level of input on graphic syntax theory. This asymmetrical relationship between content and form is further evident when publishers employ external reviewers who appear to evaluate the manuscript only. Only one interviewee mentioned external reviewers commenting on the diagrams [#1, p 282].

The asymmetrical relationship in formal 'reflection-on-practice' in relation to biological, pedagogical, and graphic syntax theory is concerning when seen from an information design perspective; as is the general awareness of included ineffective graphic tactics. Firstly, the potential ambiguities in the content proper message may affect the reader's experience of the diagram. This is particularly so when the diagrams are used as main carriers of information by visually oriented pupils [section 6.5.1·1, p. 237]. Secondly, it is concerning to see an asymmetrical input on biological, pedagogical and graphic syntax theory for a case of visual output which is a clear staple in the 'design lexicon' of educational publishing. More so given that a general graphic strategy, including the graphic tactics, are closely referenced when developing new composites. From an information design perspective the aim is here to develop a 'design lexicon' which includes an effective visual output with precise graphic tactics; a well-operating machine (Doblin, 1980: 104) through clear logos (Buchanan, 2001: 195-197). The current information transformation rationale, as identified through this research enquiry, thus sets the ground for investigating the possibility of an alternative, informed by the research findings of this enquiry, and information design theory.

Summary

This chapter has presented the findings based on the *second research strand* in this research enquiry.

The current rationale for transforming information into ecological cycle network diagrams in educational publishing was here identified by analysing the gathered interview data. This analysis was based on viewing the professional practice context as part of a design situation and defining the individual publisher's practical setting as the situational context surrounding the design problem.

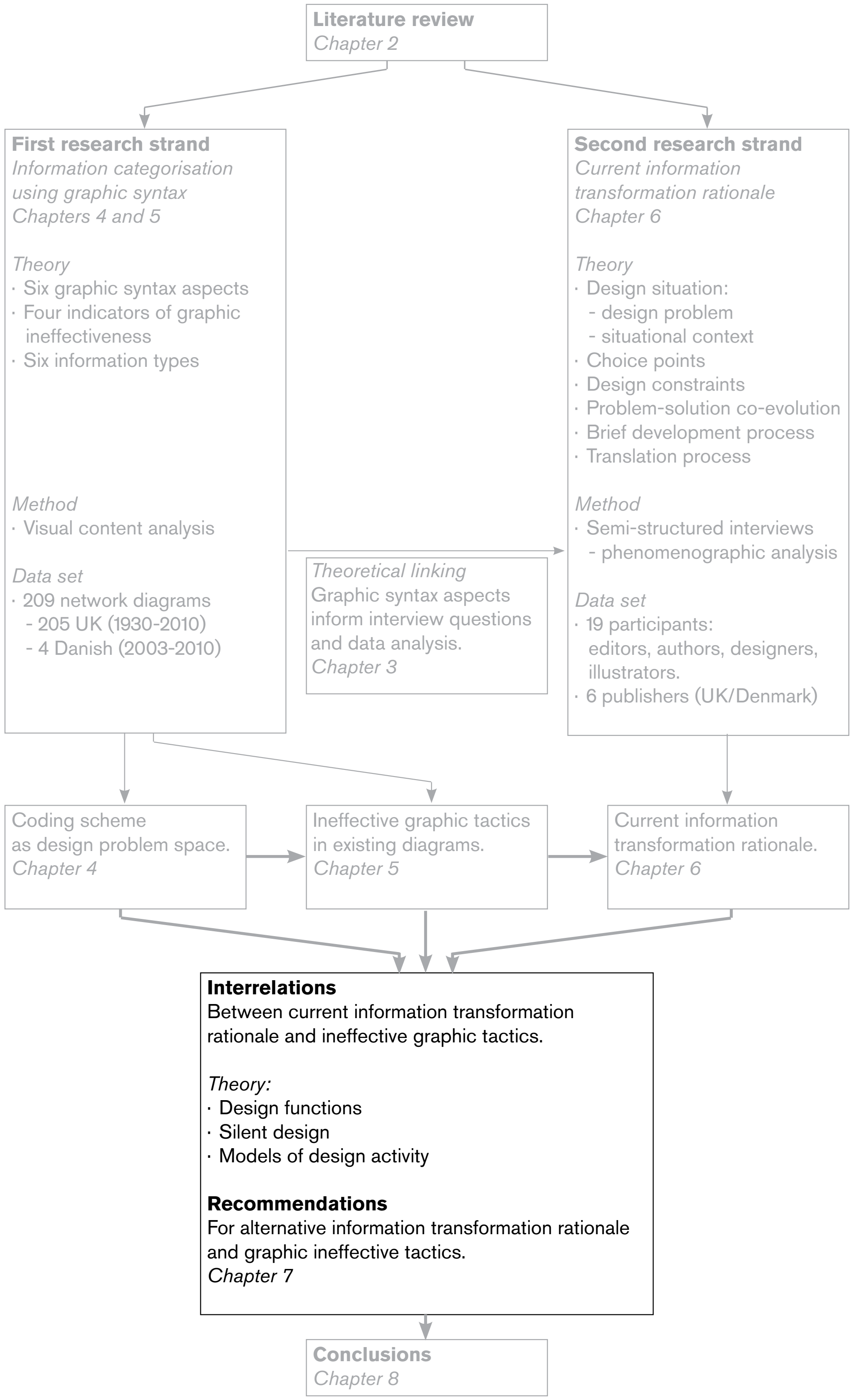
A cross-sectional analytical perspective on the design situation identified the features attended to at choice points, variation in approaches, and the reasoning guiding the decision-making in the brief development and translation processes.

A process oriented view of the design situation revealed how the participants navigate among the choice points, and the organising principles found for each point. The process sequences were presented in relation to four identified brief types.

Combined the analyses revealed an information transformation rationale severely constrained by a given solution: the graphic strategy is largely inevitable, set by the exam specifications and the nature of ecological cycle subject. This leads to regularly creating composites of existing ecological cycle network diagrams.

Interviewees were aware of ambiguities and ineffective graphic tactics in the visual output and suggested improvements to the current practice. Thereby this chapter concluded that the possibility for an alternative information transformation rationale may be investigated based on the research findings of this enquiry, and information design theory.

7 Current information transformation rationale and alternatives



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Contents

7 Current information transformation rationale and alternatives

7.1 Introduction

The research findings presented so far in this thesis have revealed the theoretical and professional practice context of ecological cycle network diagrams. These findings are now integrated to investigate how ambiguities come to exist in ecological cycle network diagrams in science text books for the 14-18 years age groups. This analysis aims at identifying how an alternative information transformation rationale may be defined, based on the research findings and information design theory.

7.1.1 Integrating research findings

The findings contributed so far by this research enquiry are now integrated to identify how the reasoning when defining and planning a source content, analysing the source content, and composing an ecological cycle network diagram – *ie,* the information transformation rationale – may affect the occurrence of ineffective graphic tactics. This analysis is enabled by identifying the models of design activities present in the investigated professional practice context (Dumas and Mintzberg, 1991). Models of design activities are here identified by the formal and informal delegation of responsibility as described at each choice point in the information transformation process [section 7.2, p. 315].

The interrelations between the models of design activities, potential theoretical complication, and ineffective graphic tactics are then analysed to reveal any plausible implications of design decisions in relation to ambiguities in the visual output [section 7.3, p. 321]. This analysis suggests that a direct relation exist between the decision-making in the professional practice context and the effectiveness of the visual output. Thus the identified interrelations between design decisions and ineffective graphic tactics enable investigation of how well the current information transformation rationale matches the setting of an ill-defined design problem.

Based on these findings, it is possible to suggest a set of recommendations for an alternative information transformation rationale, aimed at improving the effectiveness of the visual output. These recommendations build on suggestions from the interviewed participants, the integrated research findings, and information design theory. The recommendations serve to meet the practice-led aims of this research, *ie,* reflecting on, and enhancing practice, as well as analysing theoretical and practical difficulties for the enhancement (Woolley, 2000b) [section 1.5.2, p. 17]. The integration of research findings thereby demonstrates how information design theory and descriptive models of design may be utilised to review current practice, and the findings used to improve future practice. This demonstration is facilitated by the direct link between theory, visual output, and professional practice context in this research enquiry.

7.1.2 Linking of theory, visual output, and professional practice context

In this research enquiry the theory, visual output, and professional practice contexts are bridged using a methodological approach of a linear inductive path. A theoretical link between the two *research strands* was provided by structuring the interview guide based on the analysed graphic syntax aspects and the findings from the pilot visual content analysis [section 3.1.1.1 p. 68]. Furthermore, the definition of the coding scheme for the visual content analysis, as representing the investigated design problem space [section 4.5, p. 155], sets the ground for analysing interrelations between the identified information transformation strategy, tactics, and design decisions.

7.1.2.1 Information transformation strategy and tactics

To facilitate the analysis of interrelations between the theoretical and professional practice context, information transformation was here defined as consisting of three levels of decision-making [section 2.1.3.1-2, p. 28]:

- *Information transformation strategy*
  The defining, and planning of the source information, for example, deciding to include visuals in the first place, and defining the source biological content.
- *Information transformation tactics/graphic strategy*
  Analysing the defined source content and deciding diagram type.

Decision-making here relates to the overall dimension of the design problem space [section 6.2.2, p. 225].

- *Graphic tactics*
  Selecting and organising graphic objects and graphic relations within a graphic syntax aspect to represent an information type. Decision-making here relates to the sub-dimension of the design problem space [section 6.2.2, p. 225].

This distinction facilitates identification of those responsible for the different levels of decision-making in the identified design processes, and in turn the participants responsible for different design functions at each level.

7.1.2.2 Design functions and design constraints

Dumas and Mintzberg's model of design functions (1991) is applied here to identify the delegation of responsibilities in relation to design functions at each level of decision-making. Their model of three design functions – 'function', 'fit,' and 'form' – was adapted to the focus in this enquiry [section 2.4.5.1, p. 50]:

- 'function' – relates to the biological accuracy of the diagram
- 'fit' – describes the alignment between the diagram and the reader needs, and relates to two sub-categories of functions:
  – 'conceptual fit' describes the alignment between diagram and curriculum purpose, pedagogy, and production capacities.
  – 'technical fit' describes the cognitive ergonomics of the diagram, *ie,* the precision of graphic syntax in relation to the reader's perception process.
- 'form' – relates to the aesthetics of the diagram.

Crucially, the identification of responsibility in relation to 'technical fit' here reveals the participants providing the core information transformer input in relation to the different levels of decision-making [section 2.4.5.1, p. 50]. Essential input for this analysis is provided here by the internal and external constraints identified through the two *research strands.* These findings have revealed the room for manoeuvre for the information transformer for each level of decision-making. The room for manoeuvre here relates to whether a problem-solution pairing is affected by inherent complication in the design problem space in addition to features in the situational context.

7.1.3 Research findings to integrate

Overall, this research enquiry has revealed the ecological cycle network diagram as a staple in the 'design lexicon' of educational publishing. This status was reflected, firstly, by the ubiquity of the network diagram in textbooks that visualise the subject [section 3.2.2, p. 75]. Secondly, by the visual output being prescribed by exam specifications or generally anticipated in exam questions. This status underpins the information design-led aim of an effective visual output. Three sets of research outcomes are here integrated to analyse how the current rationale facilitate the meeting of this aim.

7.1.3.1 An ill-defined problem space

The first set of findings derives from the development of the visual content analysis coding scheme. The units of analysis were here defined by synthesising the analysed graphic syntax aspects, indicators of graphic ineffectiveness, and general information types in ecological cycle network diagrams. This allowed for defining the units of analysis, *ie*, coding values, as general graphic tactics, and identifying general ineffective graphic tactics among them. An ineffective graphic tactic may result in an ambiguous content proper message. The general graphic tactics here represent the internal constraints of the design problem space for a network diagram [figure 4.51, p. 154]. A problem space which is generally ill-defined due to the number of conflicting, and complicated interrelations within and between the graphic tactics, and their effects on the content proper message [section 4.5.1, p. 155].

7.1.3.2 Effects of ineffective graphic tactics

The second set of research findings derives from the frequencies of the coding values within the UK and Danish data sets (205 UK Diagrams and four Danish). These frequencies identified the information categorisation in existing visual output, including the general ineffective graphic tactics. Further analysis of these frequencies identified additional – ecological cycle specific – ineffective graphic tactics, arising from combinations of coding values [table 5.1 p. 203]. This unravelled the design problem space specifically for an ecological cycle network diagram. Within this ill-defined problem space, the ineffective graphic tactics represent ineffective sub-problem solution pairings. These ineffective pairings were found to potentially affect both the content proper message and the options at interrelated graphic syntax aspects. The general effects on the content proper message of the identified ineffective graphic tactics include:

- Ambiguity about the nature of included content proper elements – *eg,* implicit nodal points representing a possible 'hidden' element.
- Ambiguity about the role of included elements as connecting or connected – *eg,* organisms appearing to be in circulation.
- Illogical linking sequences arising from confusion about chemical transfer, and transformations, and several processes implicitly represented in the same graphic object [section 5.8.1.1, p. 207].

The conflicting interrelations between graphic tactics may be due to:

- The general nature of graphic syntax which results in graphic syntax aspects creating categories of information whether applied intentionally or unintentionally. An example here is the application of bold type which may emphasise nodes, although the concepts represented by nodes and connectors are of equal importance.
- The nature of the ecological cycle content proper in relation to graphic syntax, *eg*, representing a process in a connector role, may dislocate the processes outside an organism [section 5.8.1.2, p. 208].

This set of research findings underscores the challenge posed by this ill-defined problem space when aiming at an effective visual output, *eg,* a 'well-operating machine' (Doblin, 1980: 104), with a precise logos (Buchanan, 2001: 195) [section 5.9.1, p. 212]. A precise logos in turn points towards the activities of defining and planning the source content, and effectively composing the visual output, *ie,* the information transformation rationale.

7.1.3.3 Current information transformation rationale

The third set of research findings arose from the *second research strand,* revealing the current information transformation rationale. For this analysis, the professional practice context was seen as the situational context surrounding the design problem in the design situation. A cross-sectional view here identified organising principles at choice points in the brief development and translation process. Key influences among these external constraints [figure 6.42, p. 290] were identified as the exam specifications and the biological nature of the content proper [section 6.7.1, p. 289].

A process oriented view of the design situation identified the co-evolution of the problem-solution spaces (Dorst and Cross, 2001) [section 6.6.3, p. 283]. This revealed the brief development as the problem setting process led by author and editor. The brief development itself results in either inflexible or flexible briefs ranging from re-using an existing diagram to sketching a new, with room for exploring general aesthetics, visual attributes, the pictorial objects, typographic hierarchies within nodes or arrow labels respectively, and tweaking the overall spatial organisation within the given space [section 6.5.7, p. 265]. Further to this, the current rationale was found to prioritize theoretical input on biological and pedagogical theory compared to that on graphic syntax theory, although the participants stated awareness of ambiguities within their visual output. The identified nuances in decision-making for the graphic syntax aspects facilitate further analysis of the delegation of – formal and informal – responsibilities to reveal the models of design activities within the professional practice context.

7.2 Models of design activities in current practice

Models of design activities (Dumas and Mintzberg, 1991) are identified here by the delegation of informal and formal responsibility, as described at each choice point in the identified information transformation process. An apparently well-defined approach to the design problem here has several implications for the delegation of responsibilities within the professional practice context investigated in this enquiry.

7.2.1 A well defined approach

The current information transformation rationale, as identified by this research enquiry, reveals that the design of an ecological cycle network diagram generally appears to be approached as a well-defined, *ie,* predictable design problem (Rowe, 1987). This approach appears led by the inevitability of the overall solution. The predominant external constraint – the exam specifications – here provides the diagram type, the majority of the biological content, and an external goal for the diagram: to prepare pupils for the exam questions in which the diagram is likely to appear. The well-defined approach is reflected when re-using existing diagrams which omits or severely limits the transformation activity as well as in the flexible briefs [section 6.5.7, p. 265]. Here the sub-dimension also appears as a set of well-defined sub-problems for which limited room for iteration is available – limited to adding biological content, visual attributes, or aesthetic adjustments.

A well-defined approach results in the field engaging with Pahl and Beitz's variant design (1988), similar to Dumas and Mintzberg's routine product, 'where little creativity or innovation is expected' (1991: 27). This routine is established, and accepted, across the investigated practical field; generally creating variants or composites of the same graphic strategy [section 6.5.6, p. 260]. Such well-defined process has several plausible implications for the current information transformation rationale:

- A well defined approach encourages decomposed design [7.2.1.1, p. 316.
- Decomposed design results in casting editors and authors as 'silent designers' [7.2.1.2, p. 317].

- This delegation of responsibility affects the input and overview of 'conceptual fit' and 'technical fit' in the information transformation process [7.2.1.3, p. 319].

This in turn affects the quality of the visual output.

7.2.1.1 A well-defined process encourages decomposed design

With the exception of re-using an existing diagram – which involves no active transformation – the identified information transformation processes represent 'decomposed design' (Dumas and Mintzberg, 1991) [section 2.4.5.2, p. 52]. This results in a design situation reminiscent of an assembly line along which different participants develop separate elements of the diagram (Dumas and Mintzberg, 1991). This is evident from the delegation of responsibilities for different choice points to different people [figures 6.38-6.41, p. 285]. This decomposition of design functions generally appears across the investigated field of practice, however the practical settings in the UK represent deeper decomposition than those in Denmark. The design process at investigated UK publishers is decomposed at the synopsis stage [section 6.4.1, p. 233], the brief development – where UK editorial teams include several formal roles, and on the design side – where the UK publishers may out-source the design of the book concept, template, type setting, and the actual book design to different people.

From a design management perspective, decomposed design increases the ease of planing and managing the process. Within this model of design activities, each participant knows his or her own specific role and that of the others. More significantly, everyone is aware of the expected overall outcome, here specified by the curriculum purpose and/or anticipated exam questions. The publishers thereby know what to expect from the design of an ecological cycle network diagram within their own and their competitors' processes. These expectations are further supported by the nature of developments in the biological content, at the level of detail included for the 14-18 years age groups, which has remained constant throughout the years investigated in this research enquiry (1930-2010) (Mackenzie *et al*, 2004). New biological knowledge, provided by increased scientific research, has instead filtered through as subject context[1]. In Akin's (1984) terminology, the main design parameters – diagram type and biological content – have remained constant, leaving only limited variable parameters.

Limited variable parameters and decomposed design result in any graphic exploration generally deriving from isolated 'chimneys' (Dumas and Mintzberg, 1991: 28), and focused on individual graphic tactics, for example, applying visual attributes to differentiate chemical energy from processes[2] [#12, section 6.6.1.3, p. 275]. From an information design perspective, this stagnation in visual exploration is concerning, given the frequencies of ineffective graphic tactics identified through this research enquiry. The field of practice here appears stagnated around a set of visual outputs which are potentially ambiguous. This ambiguity was demonstrated through the visual content analysis in this research enquiry, and mentioned by several interviewees [section 6.6.2.2, p. 279 and 6.5.6.2, p. 262]. Interestingly, the constrained room for manoeuvre and limited variable parameters in which the participants engage, is the space from which ineffective graphic tactics originate. The editors and authors' role as 'silent designers' (Gorb and Dumas, 1987) contributes to this.

7.2.1.2 Editors and authors as 'silent designers'

In chapter 6 [section 6.5.7, p. 265] the brief development process was identified as the problem setting process within the investigated practice context. The delegation of responsibilities in the brief development here results in editors and authors serving as 'silent designers' (Gorb and Dumas, 1987), *ie,* participants performing design related activities, contributing to the design, but not formally acknowledged as 'designers'. Table 7.1 [next page] summarises the generalised decomposition of responsibility in relation to the overall and sub-dimension of the design problem.

1 For example, older books discuss the core cycle principles and industrial production context only (*eg,* Andreade, 1937), whereas contemporary publications (*eg,* Piekut *et al,* 2005 and Dawson, 2005) include environmental implications.

2 The 'chimneys' may provide rare single instances of alternative graphic strategies. Such examples are discussed in section 7.4.3. p. 332.

Brief types b)-d)	[Page layout]	Brief	Evaluation	Translation	Evaluation
Diagram type		Author/ Editor	Editor		Author/ Editor
Biological content		Author/ Editor	Editor		Author/ Editor
Node and connectors		Author/ Editor	Editor		Author/ Editor
Spatial positioning		Author/ Editor	Editor		Author/ Editor
Pictorial objects/ aesthetics			Editor	Illustrator	Author/ Editor
Verbal syntax		Author/ Editor	Editor		Author/ Editor
Visual attributes	Editor/book -designer/ Author		Editor	Diagram designer/ Illustrator	Author/ Editor
Typography	Editor/book -designer/ Author		Editor		Author/ Editor

Table 7.1: Generalised skills delegation in relation to graphic syntax aspects.

Analysing this delegation of responsibility in relation to the 'function', 'fit', and 'form' design functions (Dumas and Mintzberg, 1991) [section 7.1.2.2, p. 311] reveals the participants providing the core information transformer input in the investigated professional practice settings. As silent designers the editors and authors are responsible both for biological accuracy and alignment of the diagram to the reader's needs. Thereby the silent designers oversee both the 'function' and 'fit' design functions (Dumas and Mintzberg, 1991). The responsibility for the 'conceptual fit' is fragmented according to the individual participants skill sets, *ie,* authors generally contribute practical teaching experience, editors are in charge of budgets and time schedules, and both may contribute curriculum and pedagogical knowledge. The 'technical fit' – cognitive ergonomics – is primarily the responsibility of the person who sketches the diagram in the brief. Thereby the identified delegation of responsibility results in editors and/or authors performing the main information transformer role in the investigated professional practice settings. This affects the input and overview of 'conceptual fit' and 'technical fit' in the process.

7.2.1.3 ‘Conceptual fit’ and ‘technical fit’ design functions

Casting the editors and authors in the roles as information transformers leaves the designer/illustrator to oversee mainly the aesthetic ‘form’ design function. The designers/illustrators here contribute graphic software skills, drawing skills, and tacit knowledge about information design. An exception to this ‘stylist’ role is the designer in the designer-author team, who has formal biological knowledge. However, this person’s graphic syntax knowledge is tacit. Such division between the ‘function’ , ‘fit’, and ‘form’ design functions (Dumas and Mintzberg, 1991) reflects Kostelnick’s (1994: 96) ‘dress metaphor’, the designer here ‘dressing’ the author’s thoughts.

Gorb and Dumas (1987) encourage the acknowledgement of silent designers’ contribution to the process:

> ‘To assume that if the job entails design, it should be undertaken by a professional designer is to adopt an over simplistic view. The individual undertaking the work, oblivious of its design content, may well be operating effectively. The ‘design’ part of this work will in his terms be classified differently and his motivation and approach toward the task is likely to be entirely different from that of the professional designer. Indeed within his particular business context his set of decisions might be more appropriate than those of the designer.’ (Gorb and Dumas, 1987: 152).

The contributions of editors and authors as ‘silent designers’ in relation to the ‘function’, ‘conceptual fit’, and ‘technical fit’ design functions are indeed important for an ecological cycle network diagram. The integral role of the ‘silent designers’ is also, within the current rationale, validated by a well-defined approach which assumes a low design requirement (Akin, 1984; 1988). However, the casting of ‘silent designers’ as the main information transformers creates an asymmetrical relationship in the input on ‘conceptual-’ and ‘technical fit’ respectively.

The ‘conceptual fit’ design function appears well-informed in the current process through input on pedagogical theory, biological knowledge, curriculum level, and teaching experience, *eg,* in the identified evaluation criteria [section 6.5.5, p. 256; section 6.6.2, p. 277]. However, the 'technical fit' design function appears de-prioritized. The authors with strong visual skills are self-trained in this aspect and the interviewed designers operate on tacit knowledge. For example, no interviewee expressed formal awareness of *eg,* Gestalt theory, or mentioned that they actively research graphic syntax theory. Tacit knowledge, as an 'accumulated wisdom of design experience' (Macdonald-Ross, 1977: 185) cannot be disregarded and is considered an integral part of the design process (Schön, 2006). However, no interviewee in the data set represents an informed overview of the 'technical fit' expertise needed to ensure effective graphic tactics. Consequently the current information transformation is predominantly biology and pedagogy-led, rather than graphic syntax-led. Combined with the well-defined approach and decomposed design, this finding suggests that the current information transformation rationale is mismatched with an ill-defined design problem.

7.3 Current information transformation rationale in relation to an ill-defined design problem

Interrelations between decomposed design and the potential theoretical complication posed by an ecological cycle network diagram are here analysed to reveal any plausible implications of design decisions in relation to ambiguous visual output. Such plausible implications suggest a direct relation between the current information transformation rationale and effectiveness of the visual output.

7.3.1 Potential theoretical complication

The identified well-defined approach, decomposed design, and general emphasis on 'conceptual fit' expertise in the current information transformation rationale appear mismatched with an ill-defined design problem. The mismatch arises, firstly, from potentially complicated interrelations between graphic syntax aspects, secondly, from the nature of the ecological cycle content proper in relation to graphic syntax, led by complicated interrelations within the biological content [7.1.3.2, p 7·6]. Such potential theoretical complication require several trade-offs, *ie,* choosing the advantages of one graphic tactic over another whilst considering the interrelations and complications of the solution. Consideration of such trade-offs is necessary if the intention is to reduce the ambiguity (Le Novère *et al*, 2009; Bertin, 1983). This highlights a mismatch between the model of design activity reflected in the current rationale and the design of an ecological cycle network diagram. This mismatch has several plausible implications for the effectiveness of the visual output, because:

- Decomposed design prevents an informed and systematic overview of the complicated interrelations between graphic tactics, and biological content, and required trade-offs [section 7.3.1.1, below].
- An overview of the complicated interrelations between graphic tactics, and biological content, and required trade-offs suggests that the graphic strategy is mismatched with the nature of the biological content [section 7.3.1.2, p. 323].

This may contribute to the occurrence of ineffective graphic tactics.

7.3.1.1 Trade-offs between graphic tactics

Graphic tactics in ill-defined design problems require trade-offs when the interrelations between the individual sub-problems and the implications of their connections are contradictory (Rowe, 1997; Dorst and Cross, 2001). The interrelations between graphic tactics in an ecological cycle network diagram – as analysed in this research enquiry – are summarised in table 5.1, [p. 203]. This table reveals several potential trade-offs linked to the indicators of graphic ineffectiveness. For example, the occurrence of polysemy [section 4.3.2.2, p. 110] is a trade-off for simultaneously categorising several information types within visually similar nodes or connectors. Similarly, the inherent conflict between the natures of ecological cycles and syntactic roles necessitates trade-offs such as dislocating a process, *eg,* photosynthesis, outside a pictorial plant if opting for exclusively conceptual linking [section 5.2.3.3, p. 172]. Likewise, implicit or imprecise nodes [section 4.3.2.2, p. 110] may be trade-offs needed for accommodating a given number of graphic objects in the given space. To these complications are added theoretical recommendations, *eg,* equal emphasis on non-hierarchial elements (Bertin, 1983), which may require trade-offs – in the form of inconsistency [section 4.3.2.2, p. 110] – when visually distinguishing nodes and connectors.

Each potential trade-off needs informed consideration during the problem setting process. This results in a 'messy' problematic situation (Schön, 2006: 47). Such a situation requires an overview of the binding implications and effects of each graphic tactic during the co-evolution:

> '…and if they are good designers, they will reflect-in-action on the situation's back-talk, shifting stance as they do so from "what if?" to recognition of implications, from involvement in the unit to consideration of the total, and from exploration to commitment.' (Schön, 2006: 103)

A single arrow label is here a particularly elucidating example. An arrow labelled with the noun 'photosynthesis' indicates the process as a conceptual connection, but may also be read as the process in movement. Furthermore, the process is dislocated outside the plant location, and the noun verbal syntax may create association to other – connected or connecting – text objects as may any visual attributes. Alternatively, an unlabelled arrow results in the element in the source node appearing to be in movement. Unfortunately, a systematic overview of these interrelations is excluded from the current information transformation rationale which consists mainly of linear paths through the sub-problems, transferring limited rooms for manoeuvre from one choice point to another. With the exception of divergent iterations [section 6.6.2.3, p. 279], the 'reflective conversation' in current practice is limited and the instances of interrogation fragmented [section 6.7.5, p. 303]. The current rationale thereby appears to prioritize a focus on the overall, external characteristics of the design problem, the graphic strategy and individual graphic tactics, compared to the complicated interrelations between graphic tactics. The asymmetrical focus on external and internal characteristics of the design problem in turn leads to overseeing an underlying critical issue with the graphic strategy. Here the graphic strategy appears mismatched with the inherent complicated interrelations in the design problem due to the nature of the biological content.

7.3.1.2 Relation between graphic strategy and biological content

Parallel with the complicated interrelations between graphic tactics runs a set of equally complicated interrelations in the content proper represented by an ecological cycle network diagram. These complications arise from the different natures and roles of the biological elements, as indicated by the general ambiguities emerging from the 29 ineffective graphic tactics found by this research enquiry [section 7.1.3.2, p. 312]. These general ambiguities suggest that the current graphic strategy itself may represents a trade-off in relation to general graphic effectiveness: a single network diagram may be insufficient for accommodating the required information types and their complicated biological interrelations.

A similar conclusion has been drawn by a group of biochemistry scientists addressing the issue of ambiguity in network diagrams of biochemical systems (Kitano, 2003; Kitano *et al,* 2005; Kohn and Aladjem, 2006; Le Novère *et al,* 2009). Their focus was prompted by finding visually similar arrows – within the same diagrams – representing, *eg,* activation, transition of state, or translocation of material (Kitano, 2003; Le Novère *et al,* 2009). Kohn and Aladjem (2006: 1) relate the found ambiguity with 'the enormous amount of information that needs to be conveyed for each participant in the network and the cross-connections between pathways'. This group of scientists – working towards a standard notation for biological networks[3] – address the biological complexity by using three complementary diagrams: a process diagram, an entity relationship diagram, and an activity flow diagram (Le Novère *et al*, 2009: 736). Together the three diagrams provide a general landscape – the activity flow diagram – and more local detail on processes or entity relations. Table 7.2 lists the defining features of these diagram types and the involved trade-offs.

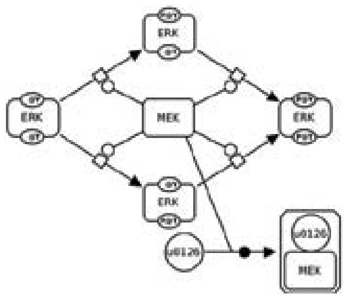
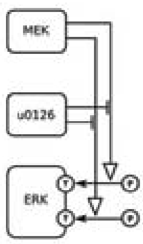
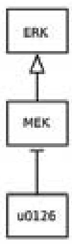
	Defining feature	**Trade-offs**
Process diagram 	· Shows temporal sequence of reactions and route pathways. · Traces entities through series of transformations and sequences. · Emphasis on transformations. · Shows all processes and interactions taking place over time.	· Same element appears several times in different states.
Entity relationship 	· Interaction among entities. · 'Snap shot' of interactions at one point and place in time. · Emphasis on how one entity may affect another. · Each entity appears only once. · Reader does not have to trace routes of entity in different states.	· Temporal order is implicit. · Sequence of event is difficult to understand.
Activity flow 	· Provides general overview on abstract level of system. · May show concentration levels of included matter.	· Lack of detail.

Table 7.2: Complementary diagrams suggested by Le Novère *et al*, 2009. Information is synthesised from (Kitano, 2003; Kitano *et al*, 2005; Kohn and Aladjem, 2006; Le Novère *et al*, 2009).

3 This notation system is discussed in section 7.4.3, p. 332.

The separation of features to visually elucidate here represents a priority of increased clarity over a single overview of a cycle's many features (Le Novère *et al*, 2009: 737). This graphic strategy is an interesting alternative to the diagrams investigated in this enquiry, which represent general overviews of the cycles. In the curriculum level aimed at the 14-18 years age groups the number of biological elements, and interrelations are reduced compared to the higher scientific levels. However, the fundamental nature of the ecological cycles as systems and networks remains. The graphic strategy – of accommodating the entire biological system in one network diagram – may thus explain why individual node-connector-node combinations in existing diagrams represent features of all three diagrams outlined in table 7.2, *ie*, both chemical transformation, transfers, and a general overview [section 5.8.1.2, p. 208]. In some cases all three features are present within one nodal text object due to prepositions, and active and passive voices in verb phrases. The graphic strategy of a general overview may thereby contribute to the resulting illogical linking sequences and fundamental mixed, and ambiguous, messages. This reveals a link between decisions about graphic strategy and ambiguities in the visual output.

7.3.2 Plausible implications of design decisions in relation to ambiguities in visual output

The integration of the findings from this research enquiry has identified several plausible implications of the current information transformation rationale in relation to ambiguities in ecological cycle network diagram. The model of design activities generally present in the investigated professional practice context – decomposed design – here represents a significant external constraint on the information transformation process. This external constraint potentially prevents a systematic and informed overview of 'technical fit', resulting in less consideration of interrelations between the internal constraints, *ie*, graphic tactics. The plausible implication of this is less reflection on the graphic strategy, and its match to the nature of the represented content proper. This is concerning, given the reflection on the graphic strategy contributed by this research enquiry. The findings here suggest that the design of an ecological cycle network diagram requires interrogation and systematic overview of the complicated interrelations between graphic tactics, between the biological elements, and between the two. The need for reflection on the existing graphic strategy is further underpinned by the conclusions from Le Novère *et al* (2009). Interestingly, the work from Kitano (2003), Kitano *et al* (2005), Kohn and Aladjem (2006) and Le Novère *et al* (2009) also represents a change in the variable design parameters for the design problem investigated here. Where the biological content for ecological cycle network diagrams at curriculum levels for the 14-18 years age groups have remained constant [section 7.2.1.1, p. 316], higher scientific levels are now contributing research-based input for the graphic side of the overall problem space investigated in this research enquiry. This provides further incentive for exploring an alternative information transformation rationale.

7.4 Recommendation for alternative information transformation rationale

Based on the integration of research findings, it is possible to suggest a set of three recommendations for an alternative information transformation rationale. This aims at improving the effectiveness of ecological cycle network diagrams in future practice – here the field of design practice rather than that of a specific publisher or individual participant. These recommendations build on suggestions from the interviewed participants, the integrated research findings, and information design theory, and relate to the different levels of decision-making within information transformation.

7.4.1 Recommendations for different levels of decision-making

The recommendations contributed through this thesis relate to each of the defined levels of decision-making in information transformation – graphic tactics, graphic strategy, and information transformation strategy:

- The first recommendation is to enhance the effectiveness of individual ineffective graphic tactics within ecological cycle network diagrams, by considering related graphic syntax theory. For this aim the checklist developed in chapter 5 [table 5.1, p. 203] is here expanded with recommendations to address the 29 ineffective graphic tactics as individual sub-problems [section 7.4.2, below]. However, this once again highlights the complicated graphic interrelations, leading to recommendations aimed at addressing the graphic strategy.
- The second recommendation is to explore an alternative graphic strategy of complementary diagrams [section 7.4.3, p. 332]. For such exploration it is recommended to address the current participant set up.
- The third recommendation is a call for the integration of a graphic syntax-led information transformer into current practice to increase the 'technical fit overview' [section 7.4.4, p. 335].

7.4.2 Addressing individual graphic tactics

An expanded checklist is here provided for participants focused on addressing individual ineffective graphic tactics within ecological cycle network diagrams [Table 7.3, A3 fold out]. This list outlines graphic syntax-based actions that can be taken to address the – general and ecological cycle specific – ineffective graphic tactics. Rather than a prescriptive list, table 7.3, presents an overview of the different options to consider within each graphic syntax aspect. The general level of each action means they can be implemented as check points by any existing participant. However, addressing ineffective graphic tactics as individual sub-problems is aligned with a well-defined approach to the information transformation [section 7.2.1, p. 315]. Given the ill-defined nature of an ecological cycle network diagram, this checklist is limited to providing overall guidelines for navigating the conflicting interrelations. For navigating these interrelations, participants are recommended to consider the role and nature of each information type included, their interrelations, and the logic of the resulting linking sequence. However, the limitations of addressing individual ineffective graphic tactics within a single diagram further underscoring the need for addressing the graphic strategy.

A3 fold out: table 7.3
check list for addressing ineffective graphic tactics.
PAGE 1

A3 fold out: table 7.3
check list for addressing ineffective graphic tactics.
PAGE 2

A3 fold out: table 7.3
check list for addressing ineffective graphic tactics.
PAGE 3

7.4.3 Addressing the graphic strategy

The alternative graphic strategy of complementary linking diagrams for ecological cycle network diagrams is demonstrated for higher scientific levels by Le Novère *et al* (2009). This set of complementary diagrams addresses the three general ambiguities – about the nature, role, and linking sequences – resulting from the ineffective graphic tactics found by this research enquiry. An example of using multiple diagrams appears within the textbook pages collected for this research enquiry [figure 7.1]. This graphic strategy separates different features of the cycle, and supplements pictorial and schematic representations.

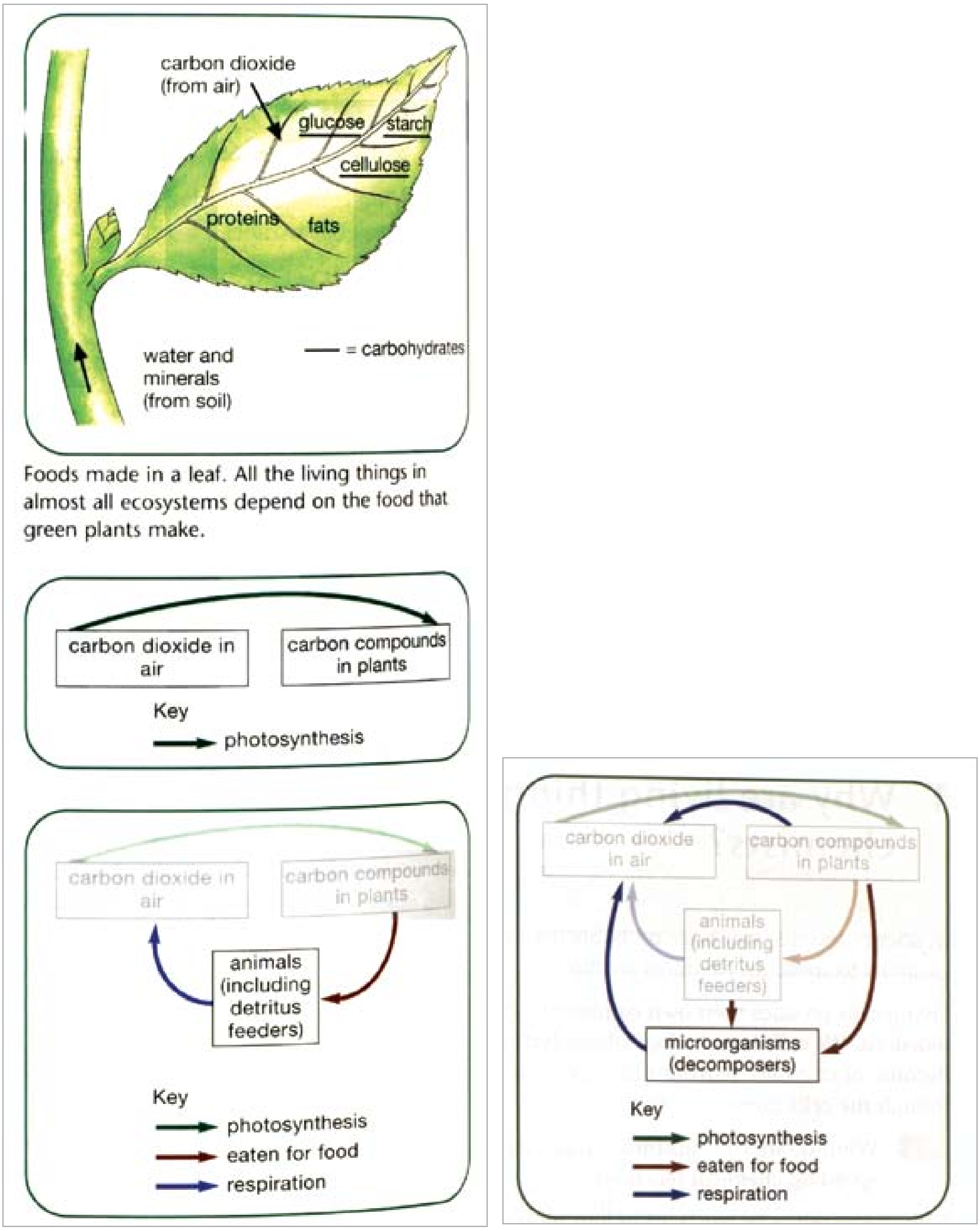


Figure 7.1: Multiple diagrams showing different features of the carbon cycle (Martin, 2006: 146-147).

This graphic strategy shows the different sub-cycles within the carbon cycle, gradually building up the general overview. Interviewed authors mentioned two obstacles to applying this graphic strategy within current practice: lack of space in the textbook format – the main obstacle – and based on practical teaching experience one author also assumed that the students read the final, general overview only rather than following the steps. Some authors instead expect the teachers to draw such gradual build-up on the black or white board in the class room.

With these potential constraints noted, it is recommended that the graphic strategy of complementary diagrams as demonstrated by Le Novère *et al* (2009) is explored. In the recommended strategy the different diagrams offer complementary features of the cycles rather than building up to a general overview. Separating the different features of the cycle reduces the ill-defined nature of the design problem and potentially increases the clarity about the complicated biological interrelations. Showing complementary features also provides additional overviews for the visually oriented pupils, who use the diagrams as their main source of information [section 6.5.2.1, p. 241]. Given these potential advantages, it seems reasonable to accept the trade-offs currently required for a set of complementary diagrams: excluding other visuals or an amount of body text from the particular textbook page. In future practice, digital media may lessen this spatial constraint.

The set of linking diagrams shown in table 7.2 [p. 324] illustrates how the designer may select different features to represent in complementary diagrams. The selection of the specific features to visualise for the 14-18 years age groups needs deciding at local level – the individual publication – depending on the focus of the body text, exam specifications, and the overall book concept. The analysis of source content to define a local variation of this graphic strategy may be informed here by reflecting on existing diagrams – using table 5.1 from this thesis [p. 203] – and considerations about the included elements in relation to their role – *eg,* as process agents – and the nature of their interrelations – *ie,* chemical transfers or transformations. Meanwhile, the graphic tactics may be theory-led by applying graphic syntax frameworks such as Engelhardt (2002) or Bertin (1983). For example, the selection could be centred around arrow types [section 4.4.3, p. 136], showing one diagram with movement arrows, one with conceptual links, and one with processes in precise physical location.

This suggested theory-led approach relates directly to the need for integrating 'technical fit' expertise – in the form of a graphic syntax-led information transformer – into current practice. Before presenting this final recommendation, it is appropriate to comment on an additional alternative graphic strategy; the standardised graphical notational system as developed by Novère *et al* (2009). It is beyond the scope and evidence provided by this thesis to recommend such a system for the 14-18 years age groups. However, some commentary is appropriate and is presented in appendix 11.

7.4.4 Integrating 'technical fit' in current practice

The recommendation of integrating a graphic syntax-led information transformer role into current practice applies to the general field of educational publishing. This recommendation aims at addressing the asymmetrical relation between 'conceptual fit' and 'technical fit' in decomposed design as found by this research enquiry [section 7.2.1.3, p. 319], and in turn the precision of the visual output. As an alternative to decomposed design Dumas and Mintzberg (1991) recommend co-operative design [section 2.4.3, p. 47]. In co-operative design, the silent designers are acknowledged as such and the participants work as a cross-disciplinary team. The participant relations identified by this research enquiry [section 6.7.3, p. 292] include some aspects of co-operative design. For example, co-authors in Denmark, in-house teams in the UK, and the UK based author-designer team. Unfortunately, the practical conditions – geographic distances and different time schedules – do not allow for fully integrated co-operative design in educational publishing. Furthermore, where co-operative design could help increase a general overview of the information transformation process, this model does not as such address the current imbalance in 'conceptual fit' and 'technical fit'. To improve the current focus on 'technical fit', a systematic and strategic overview of information design theory and practice is needed. This may be provided by integrating a graphic syntax-led information transformer role into the participant set-up[4].

4 The information transformer role is here defined based on existing literature (Neurath and Kinross, 2008; Macdonald-Ross and Waller, 2000). In practice, the role may be termed as an information designer, a visual editor, visual information editor *etc.* It is the essence, *ie,* the responsibilities, touch points, and skills which are recommended, rather than a job title.

7.4.4.1 Graphic syntax-led information transformer

A graphic syntax-led information transformer represents information design expertise and practical skills, and balances the focus on 'technical fit' and 'conceptual fit' through a general understanding of the content proper, exam specifications, audience-levels, pedagogical theory, and production capacities (Macdonald-Ross and Waller, 2000: 179). Such skills set enables informed decision-making and consideration of the involved trade-offs when deciding both graphic strategies and individual graphic tactics.

The information transformer may be freelance or in-house, however, the 'technical fit' expertise needs to be integrated at all stages of the information transformation process to address both graphic strategies and tactics. This includes the synopsis stage – to inform the overall information transformation strategy and general graphic strategies in the book concept – the editorial stage including the brief development, the translation stage, and the evaluation of the final diagram. The brief development, *ie,* the point of deciding the graphic strategy is here a crucial point for integrating the graphic syntax-led information transformer role. At this point the information transformer provides a systematic overview of the potential graphic tools, and what constitutes a 'good fit' between the content and form (Marcus, 1980). This enhances the mediation between the science authority – the author – and the reader (Macdonald-Ross and Waller, 2000). An essential information transformer requirement is thereby a critical stance towards the author's suggestions for both the graphic strategy and tactics:

> 'The transformer is the partner of the subject matter expert and not their slave…the transformer should not accept an author's instructions without critical thought. They must question and analyse until they can put the author's intentions in proper perspective.' (Macdonald-Ross and Waller, 2000: 179).

Examples of such questions are suggested by an interviewed author [#16, section 6.7.3.3, p. 295]: how the diagram complements the body text, how it addresses the pupils' everyday conceptions, what arrows are the central elements, and what needs to be deleted. The recommended author-editor-transformer relation thereby represents co-operative design (Dumas and Mintzberg, 1991), aiming at closing the existing cultural gap between biological content and graphic syntax expertise [section 6.6.1.4, p. 275]. The integration of a transformer role thus requires changes in the commissioning strategy, firstly, in relation to the points in the process at which graphic syntax expertise is integrated; secondly, in the skill set commissioned.

7.4.4.2 Skills set of graphic syntax-led information transformer

Macdonald-Ross and Waller (2000: 178) outlines general transformer skills as 'a good general education and a wide range of particular technical skills'. They provide an expanded overview of transformer skills for a more general range of institutions. The responsibilities of a graphic syntax-led information transformer for educational publishing, as recommended by this thesis are summarised in table 7.4.

Recommended skills set and responsibilities of graphic syntax-led information transformer	
1	Core skills set is graphic syntax-led, grounded in analytical and visual compositional expertise.
2	Has general knowledge in all areas of 'conceptual fit': exam specifications, audience-levels, pedagogical theory, and production capacities.
3	Crucial choice point for contributions: analysis of source content, developing graphic strategy, selecting graphic objects, and graphic relations, and sketching visual output.
4	Advises authors about what constitutes a 'good fit' between the content and form: providing analytical frameworks for preliminary graphic strategies. Has critical stance towards the authors' suggestions.
5	Mediates between the science authority and the reader by providing graphic syntax-led questions for the authors when identifying the critical features in the content proper.
6	Responsible for graphic strategies and tactics.
7	Systematic overview and knowledge about the involved complications and potential trade-offs between graphic tactics and graphic strategies.
8	Ensures systematic and theoretical underpinning of the information transformation.

Table 7.4: Recommended skills and responsibilities of graphic syntax-led information transformer.

Two general obstacles for commissioning and integrating this skill set in the current process exist, deriving from the educational publishing context.

7.4.4.3 Obstacles for integrating an information transformer role

Although several interviewees in this research enquiry suggested the integration of a visual editor or consultant into current practice, such integration of an information transformer may meet several obstacles. A primary obstacle is evident in the apparent cultural gap between biological and graphic expertise, reflecting a traditional view of design as 'styling' [section 6.7.4.3, p. 302, section 7.2.1.3, p. 319]. Two prerequisites for integrating an information transformer are, firstly, a view of information design as a problem setting process as well as a type of visual output; secondly, a view of effective graphic syntax as equally important to precision in forming the body text:

> 'In a full-length document – where information design extends to page display, graphic elements, and illustrations – the designer can create the message with visual language as wondrously supple as words. Under these condition of document production design can no longer be regarded as a treatment, a superfluous dress of thought, but rather as an integral part of the communication. The dress metaphor characterizes design as a separable language, but contemporary document design, which deeply interweaves visual language into the rhetorical process, demands rhetorical models that encompass design more thoroughly and seriously.' (Kostelnick, 1994: 100)

Thoroughly and encompassed information design would thereby require acknowledgement of the role and responsibilities of 'silent designers' in the current process, whilst integrating the graphic syntax-led information transformer role to complement and enhance the existing competencies. In addition to the cultural-based obstacle, the integration of an information transformer may meet practical obstacles, *ie,* budget constraints or company policy. A final obstacle for integrating an information transformer reflects back on the field of information design: lack of supply as indicated by a commissioning editor [#13, section 6.7.4, p. 302]. However, to increase the number of qualified information designers would partly depend on market demand. It could be speculated here, whether demand is lacking, in relation to educational publishing, due to the current information transformation rationale and 'silent designers' performing parts of the responsibility.

7.5 Overview of recommendations for alternative information transformation rationale

The recommendations put forward through this thesis aim at improving the effectiveness of visual output in future design practice in educational publishing. The recommendations contribute to meeting the practice-led aims of this research enquiry, *ie,* reflecting on, and enhancing practice, as well as analysing theoretical, and practical difficulties for the enhancement (Woolley, 2000b). This in turn demonstrates how information design theory and descriptive models of design may be utilised to review current practice, and the findings used to improve future practice.

7.5.1 Check list for recommended information transformation rationale

This thesis contributes a set of three recommendations to address occurrence of ambiguities in existing ecological cycle network diagrams. Table 7.5 [next page] presents an overview of these, and the analytical claims on which they are based.

Check list for recommended alternative information transformation rationale		
	Premise	*Recommendation*
1	· 29 ineffective graphic tactics identified in existing ecological cycle network diagrams [table 5.1, p. 203].	It is recommended to enhance the effectiveness of ineffective graphic tactics within ecological cycle network diagrams, by considering related graphic syntax theory. Check list provided with actions to address individual ineffective graphic tactics [table 7.3, p. 329].
2	· Apparent mismatch between current graphic strategy and level of complicated interrelations in biological content. The involved trade-offs suggest that a single network diagram, and general overview, may be an ineffective graphic strategy. [section 7.3.1.2 p. 323].	It is recommended to explore an alternative graphic strategy of complementary diagrams, focusing on different features of the cycles, *eg,* chemical transformations and transfers, or process agents.
3	· The current rationale generally reflects a well-defined approach, reflecting the inevitable overall solution. This encourages routine practice. [section 7.2.1, p. 315]. · Routine practice encourages decomposed design [section 7.2.1.1, p. 316] with authors and editors serving as 'silent designers' and designers as 'stylists'. [section 7.3.1.2, p. 323]. · The delegation of responsibility results in asymmetrical input between 'technical fit' and 'conceptual fit' in current practice, the information transformation being biology and pedagogy-led, rather than graphic syntax-led. [section 7.3.1.2, p. 323]. · De-prioritising 'technical fit' input prevents overview of interrelations between graphic tactics, biological content, and required trade-offs [section 7.3.2, p. 325].	It is recommended to integrate a graphic syntax-led information transformer at all stages of transformation process, in particular: · Synopsis stage · Brief development process · Diagram proof evaluation Skill-set and responsibilities presented in table 7.4, p. 337.

Table 7.5: Overview of recommendations based on analytical claims in this thesis.

The two first recommendations provide an additional premise for implementing the third; a premise which is underscored by suggestions brought forward by interviewees in this research enquiry [section 6.7.4, p. 300]. Integration of an information transformer role, in particular, will equip future practice to increase the precision when transforming ill-defined design problems into visual output; and hence improve the effectiveness of the investigated case of visual output from the 'design lexicon' of the field.

It is regrettable that the third recommendation is a direct echo of a previous call for employing information transformers in development of teaching material and training systems (Macdonald-Ross and Waller, 2000); itself an updated reprint from 1976. Since then, increased research focus on the visual output and the professional practice setting of educational publishing (Evans, 1987; Stylianidou *et al*, 2002; Amettler and Pinto, 2002; Puphaiboon, 2005) has highlighted the necessity for increasing the focus on the visual output and the methods with which it is generated. By bridging investigations of the theoretical and practical context of the visual output, this thesis demonstrates how the wider information transformation rationale needs reconsidering, if one wishes to improve the effectiveness of a visual output such as in ecological cycle network diagrams.

Such improvement would serve to meet the aims of information design practice [section 2.1.2, p. 26] and close an apparent gap between the level of precision offered by any ineffective diagram, and that expected from students as parts of the curriculum aims. The students are themselves required to:

> 'Evaluate enquiry methods and conclusions both qualitatively and quantitatively, and communicate their ideas with clarity and precision.' (DFCSA/QCA, 2007: 222)

Given this, it seems reasonable for students to expect a similar level of precision from the visuals in textbooks, especially so from a staple in the 'design lexicon' of educational publishing. The urgency of implementing an alternative information rationale is further emphasised by the current integration of digital formats within educational publishing, *eg,* interactive CD-roms (Jones, 2008), animations (Torp, 2010), and complementary Internet-based student forums (Alenia, 2010). Such formats were mentioned in detail by most interviewees, who also generate this visual output. Where this research enquiry is limited to investigating only six graphic syntax aspects from the graphic palette, digital media includes several other variables, *eg,* explicit time and motion variables (MacEachren, 2001; Koch, 2001). This increases the number of graphic syntax interrelations and the potential theoretical complication. Given that 29 ineffective graphic tactics, were found based on analysing 'only' six graphic syntax aspects, it is reasonable to assume that information transformation using digital formats requires a similar coherent and informed 'technical fit' overview to that recommended by this research enquiry.

Summary

This penultimate chapter presented the integration of research findings from the *first* and *second research strands*.

The identified current information transformation rationale was described as applying a well-defined approach to the design problem.

The investigated professional practice context was identified as representing decomposed design.

It was identified how decomposed design results in authors and editors serving as ‘silent designers’ in the roles of information transformers. This leads to an information transformation rationale which prioritizes input on ‘conceptual fit’ design functions.

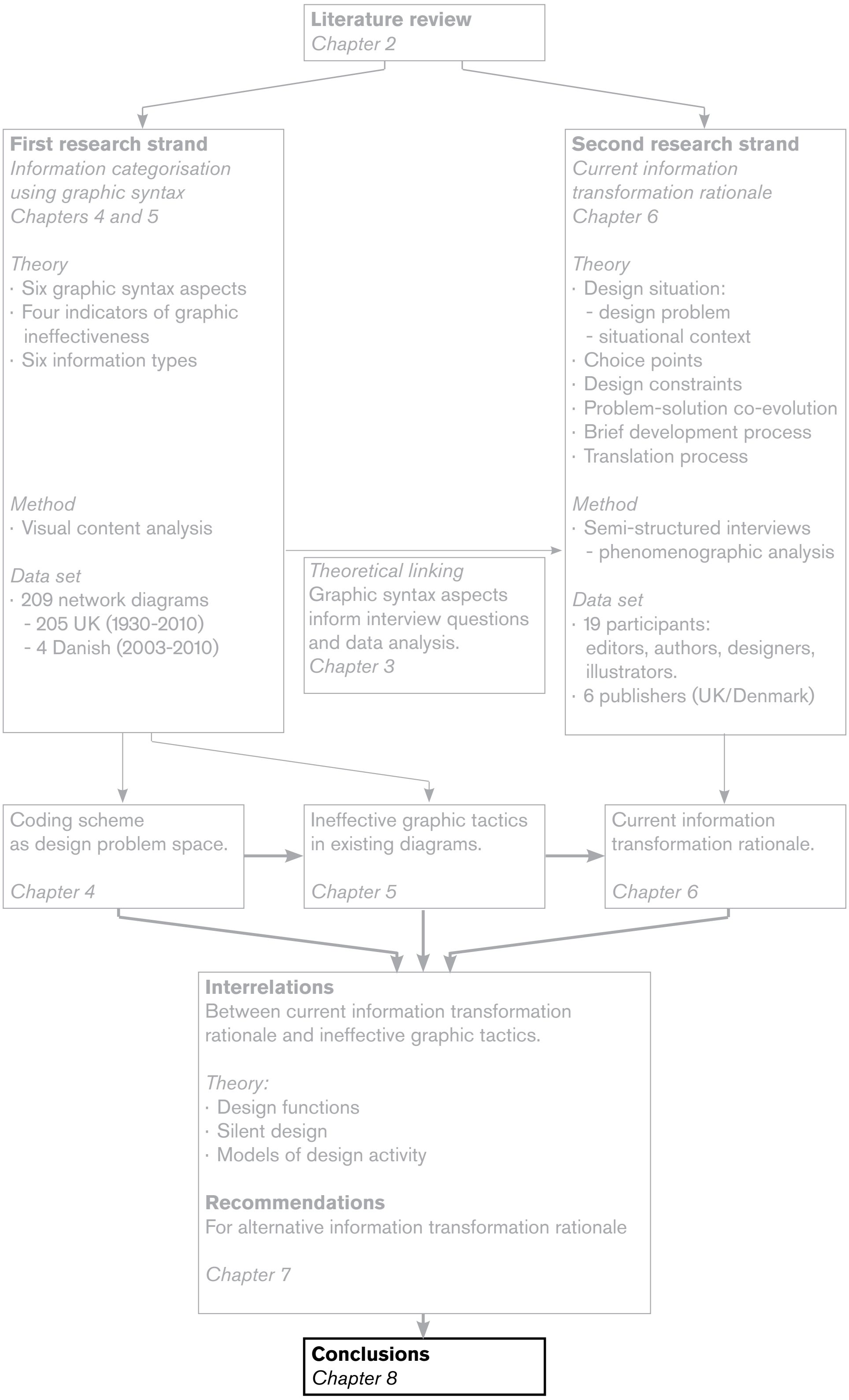
The interrelations between the models of design activities, potential theoretical complication, and ineffective graphic tactics revealed that a biology and pedagogy-led information transformation rationale and decomposed design prevent systematic overview of complicated interrelations in the design problem, and reflection on the match between graphic strategy and biological content.

It was argued that the current graphic strategy may be ineffective due to the complicated biological content, based on the visual content analysis findings and similar conclusions from related academic research

Based on these plausible implications, three recommendations for an alternative information transformation rationale were presented: to address individual ineffective graphic tactics, to apply complementary diagrams, focused on different features of the cycles, and most pertinently: integrating a graphic syntax-led information transformer role in future practice.

This chapter concluded that the integration of a graphic syntax-led information transformer role will enable future practice to meet the aims of information design.

8 Conclusions


Literature review
Chapter 2
First research strand
Information categorisation using graphic syntax
Chapters 4 and 5
Theory
· Six graphic syntax aspects
· Four indicators of graphic ineffectiveness
· Six information types
Method
· Visual content analysis
Data set
· 209 network diagrams
- 205 UK (1930-2010)
- 4 Danish (2003-2010)
Second research strand
Current information transformation rationale
Chapter 6
Theory
· Design situation:
- design problem
- situational context
· Choice points
· Design constraints
· Problem-solution co-evolution
· Brief development process
· Translation process
Method
· Semi-structured interviews
- phenomenographic analysis
Data set
· 19 participants:
editors, authors, designers, illustrators.
· 6 publishers (UK/Denmark)
Theoretical linking
Graphic syntax aspects inform interview questions and data analysis.
Chapter 3
Coding scheme as design problem space.
Chapter 4
Ineffective graphic tactics in existing diagrams.
Chapter 5
Current information transformation rationale.
Chapter 6
Interrelations
Between current information transformation rationale and ineffective graphic tactics.
Theory:
· Design functions
· Silent design
· Models of design activity
Recommendations
For alternative information transformation rationale
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Chapter 8

Contents

8 Conclusions

8.1 A meta-reflection on information design practice

This research enquiry was prompted by finding several, recurring ambiguities in ecological cycle network diagrams – *ie,* carbon, nitrogen and water cycles – in science textbooks. These initial findings led to a questioning of how such ambiguities come to exist in diagrams in recognised publications. What potential theoretical complications might affect the effectiveness of a visual output? And which features within design practice in educational publishing – in the UK and Denmark – affect the rationale when transforming a manuscript and visual references into a published diagram?

8.1.1 Bridging visual output and professional practice context

Information design is seen here as a design process and visual outputs which are focused on the effectiveness of graphic objects and their composition in relation to precise communication [section 2.1, p. 25]. A case of visual output is traced through a theoretical and professional practice context using visual content analysis, semi-structured interviews, and phenomenographic data analysis. Each context forms a *research strand*, yielding findings that are integrated to identify how design decisions may affect graphic composition. This integration of findings is enabled by basing the interview guide – *ie,* questions and sequence – on the pilot visual content analysis findings and analysed theoretical aspects. The integrated findings set the ground for recommending an alternative information transformation rationale.

Thereby this thesis represents a 'meta-reflection-on-practice' (Cherry, 2005; Schön, 2006): in this instance a practitioner standing back and observing information design practice in the context of educational publishing [section 3.1.2, p. 70]. This approach focuses on plotting the general landscape of a field of practice, rather than individual paths through the terrain. Here the outcome demonstrates how practitioners might use information design theory (Richards, 1984; Engelhardt, 2002) and descriptive models of the design process (Dumas and Mintzberg, 1991; Cross, 2000; Dorst and Cross, 2001; Lawson, 2006; Schön, 2006; Crilly, 2005) to review their practice, and use the findings to enhance it.

8.2 Visual output

Visual content analysis is applied in the *first research strand* to analyse ecological cycle network diagrams in relation to graphic syntax theory – the study of meaning created by graphic objects and their graphic relations (Engelhardt, 2002). This identifies the theoretical context of the visual output [chapter 4] and the information categorisation in 209 existing examples (205 from the UK, four from Denmark) [chapter 5].

8.2.1 Information categorisation in ecological cycle network diagrams

The coding scheme for the visual content analysis plays a central role in the *first research strand.* The scheme practically documents the units of analysis applied. These are defined to systematically identify how categories of information are created within and between nodes and connectors in existing network diagrams. Each unit of analysis represents a graphic tactic, *ie,* a selection and organisation of graphic objects and graphic relations within a graphic syntax aspect to represent an information type and its interrelations [section 2.1.3.1, p. 28]. Ineffective graphic tactics may result in ambiguous messages about the ecological cycles. Ineffective graphic tactics are here identified through four indicators of graphic ineffectiveness: implicit nodes, imprecise nodes, polysemy and inconsistency [section 4.3.2.2, p. 110]. These are informed by existing theory (Bertin, 1983; Stylianidou *et al,* 2002) and refined for this enquiry through the pilot visual content analysis.

Developing the coding scheme yields several theoretical contributions [chapter 4], namely refinement of Engelhardt's network diagram definition [appendix 4], extended detail of typographic attributes as graphic syntax aspect [section 4.4.5, p. 147], and development of verbal syntax as a graphic syntax aspect [section 4.4.6, p. 150; section 5.7, p. 200; appendix 7]. Furthermore the coding scheme demonstrates ineffective graphic tactics that apply to network diagrams in general. This enables an additional conceptual function of the coding scheme, namely representing the design problem space of a network diagram. As such the ineffective graphic tactics represent internal constraints. Given the complicated interrelations between the graphic tactics, I claim that a network diagram is an ill-defined design problem space (Rowe 1987).

Applying the coding scheme in analysis reveals the frequencies of coding values within the data set [chapter 5]. These frequencies identify the information categorisation in existing visual output, including the general ineffective graphic tactics. From these frequencies are identified additional ineffective graphic tactics. These arise from combinations of coding values and are ecological cycle specific. A total of 29 ineffective graphic tactics are found within the data set and presented in tabular form [table 5.1, p. 203]. This checklist is demonstrated as a tool for review of visual output by analysing the sample of four Danish diagrams. This analysis enables the claim that ineffective graphic tactics exist both within UK visual output (1930-2009) and current Danish visual output [section 5.8.1.3, p. 210].

In a visual content analysis a systematic review of individual units across large data sets is prioritized in favour of analysing the specific interrelations within individual diagrams. However, defining the units of analysis in relation to principles for graphic syntax here enable the claims that ineffective graphic tactics may cause ambiguity on the content proper message of individual diagrams, *ie,* the message about the ecological cycle; and that individual ineffective graphic tactics may affect interrelated graphic syntax aspects. From the list of identified ineffective graphic tactics are revealed three general effects on the content proper message, relating to ambiguity about the *nature* of included elements, their individual *role* in the cycle and the *logic* of their linking. This potentially causes confusion about matter as the essential circulating element [section 5.8.1.1, p. 207]. The underlying challenge here appears to be the simultaneous representation, within the same diagram, of chemical transfers and transformations, the elements being transferred, the process agents, and elements within which the transformations take place [section 5.8.1.2, p. 208].

Thereby the outcomes of the visual content analysis demonstrate the potential level of theoretical complication posed by an ecological cycle network diagram as a design problem. These findings are crucial for integrating the research findings in this research enquiry. The identified theoretical complication here reveal graphic syntactic features that may affect the occurrence of ambiguities in visual output, in addition to features in the professional practice setting which influence the decision-making.

8.3 Professional practice context

The analysis of the professional practice context is based on the interviewing of 19 editors, authors, designers and illustrators, at six educational publishers (UK and Denmark). The processes used for generating the visual output are identified using phenomenographic data analysis. This reveals the features within design practice in educational publishing that may affect the rationale when transforming a manuscript and visual references into a published ecological cycle network diagram.

8.3.1 Information transformation rationale

The *second research strand* in this enquiry demonstrates how phenomenographic data analysis may be applied to identify variation in practical approaches to information design within a professional context. By applying phenomenography this thesis contributes a snap shot of the current information transformation rationale as reflected at the time of the interviews. Design practice in educational publishing is here defined as a situational context, which surrounds the design problem; situation and problem together forming a design situation (Dorst, 1997). The information transformation rationale is identified through two analytical perspectives of the design situation. Both perspectives centre on significant 'choice points' (Schön, 2006) identified from existing literature and reflected in the interview guide used.

A cross sectional view of the design situation identifies the organising principles for each choice point (Rowe, 1987), which in turn reveals the external constraints on the decision making (Lawson, 2006). A process oriented view identifies how the participants navigate among these constraints, *ie,* how they perform the design task (Dorst, 1997). In this view, the design problem within the design situation is seen as a problem space and a solution space. These two spaces co-evolve, as the problem is set and diagram designed (Cross, 2000; Dorst and Cross, 2001). In this thesis the sub-problems within these spaces are the decisions about graphic tactics within each analysed graphic syntax aspect.

To enable detailed analysis of interrelations between decisions at different choice points, this thesis contributes definitions of different statuses of design decisions. Accordingly the designer may transfer sub-problems, tentative sub-solutions, or final sub-solutions between interrelated choice points [section 6.2.3.1, p. 226]. Together the two analytical perspectives identify when and how graphic tactics are decided, by whom, and how decisions at one choice point affects decisions about graphic tactics at interrelated points. This complements existing research on the design process in educational publishing (Evans *et al,* 1987; Phaiboon, 2005), by contributing finer-grained detail about nuances in decision-making.

Within the situational context identified by this enquiry the strongest influences on the decision-making are the curriculum purpose of the diagrams and the biological nature of the content. The UK exam specifications here pose a significantly greater constraint that the Danish equivalent. However, the network diagram is, in both countries, specified by the curriculum or by anticipating the diagram included in exam questions or tests. This results in a largely inevitable solution, and a design situation led primarily by solution constraints. Four different brief types are found in the investigated process, based on the artwork brief form submitted by the author to the editor. The brief type in turn affects the sequence and delegation of responsibility between authors and editors in the brief development process.

Two variations of inflexible briefs are found in the UK only, and include re-using an existing diagram, with no or minor adjustments. Meanwhile two variations of flexible briefs are found in both countries. Flexible briefs entail considerations of the biological content as supplementing or complementing the body text, and the information categorisation using nodes and connectors, pictorial objects, and arrow types. Where inflexible brief types omit or severely limit the translation process, the flexible briefs offer the designer or illustrator more room for manoeuvre (Archer, 1984). The translation here comprises the visual attributes, pictorial objects, typographic hierarchies in nodes and connectors and adjustment of the general spatial organisation, hedged by the brief specifications and any visual references.

Current practitioners demonstrate general awareness of ambiguities within existing visual output. Their reflections suggest that the general time constraints, close referencing of existing diagrams, and evaluation of the diagram in relation to other page elements simultaneously with the graphic tactics may contribute to these occurrences. Similarly significant features within the investigated professional practice context are firstly, an apparent asymmetrical relationship between the formal input on graphic syntax theory compared to that of biology and pedagogical theory; secondly, a cultural gap may appear between the authors as science authorities and the designer's visual focus [6.7.3.5, p. 298].

Based on the identified variation in approaches to information transformation, I claim that 'knowing-in-action' (Schön, 2006) dominates the decision-making. This is encouraged by the inevitability of the overall solution and results in generating composites of a generally accepted graphic strategy, which may include ineffective graphic tactics. This consensus is a concern from an information design perspective, firstly, given the status of the ecological cycle network diagram in the 'design lexicon' of educational publishing; secondly given that the diagram is described by some authors as representing the main carrier of information for some pupils. It could be asked here, whether an ambiguous diagram fully enables its general purpose of providing positive physiological and cognitive effects for the reader's processing and interpretation of the subject (Winn, 1987: 60). Further speculation includes whether ambiguity requires higher motivation from the student to approach the subject.

8.4 Integrated research findings

The findings from the two *research strands* are integrated to investigate how ambiguities come to exist in visual output from educational publishing. This analysis is based on identifying interrelations between the information transformation rationale and ineffective graphic tactics, aiming at identifying a potential alternative information transformation rationale. An alternative rationale is suggested based on suggestions from the interviewed participants, the integrated research findings, and information design theory.

8.2.1 Current information transformation rationale and models of design activity

The models of design activities occurring within the investigated publishers are identified through analysing the formal and informal delegation of responsibility (Dumas and Mintzberg, 1991; Gorb and Dumas, 1987). For this purpose this thesis contributes definition of three different levels of decision-making in information transformation, in relation to the information transformation strategy and tactics. Information transformation tactics are here recursively sub-divided into graphic strategy and graphic tactics [2.1.3.1, p. 28]. Such analysis facilitates identification of interrelations between models of design activities, theoretical complications, and ineffective graphic tactics. This reveals plausible implications of design decisions in relation to the inclusion of ineffective graphic tactics in the visual output. Based on these findings I claim that there exists a direct relation between the current rationale and ambiguities in existing visual output. Finding this direct relation facilitates further analysis of the match between the current rationale and an ill-defined design problem.

The professional practice settings investigated in this research enquiry generally appear to approach the information transformation as the problem setting of a simple, or well-defined, design problem based on a largely inevitable solution [7.2.1, p. 315]. This results in decomposed design (Dumas and Mintzberg, 1991), which encourages routine and stagnant practice [7.2.1.1, p. 316]. In this case the practice appears stagnated around a set of visual outputs that generally include ambiguity about the ecological cycles. In decomposed design the responsibility for graphic syntax-related decisions is fragmented onto several participants. This casts authors and editors as 'silent designers' (Gorb and Dumas, 1987) [7.2.1.2, p. 317] and designers as 'stylists'. In turn this leaves the information categorisation informed mainly with formal input on pedagogical and biological theory, rather than graphic syntax theory.

Finding this delegation of responsibilities leads me to claim that the current information transformation rationale is mismatched with an ill-defined problem [7.3.1, p. 321]. The fragmentation in decision-making presented by decomposed design potentially prevents systematic consideration of the complicated interrelations between graphic syntax, biological content and required trade-offs between graphic tactics. Further, the current rationale appears generally to de-prioritise systematic 'reflection-on-practice' (Schön, 2006). Combined, these aspects of the current rationale potentially lead to overlooking the ill-defined nature of designing an ecological cycle network diagram and a need for questioning the graphic strategy. This need was underscored by the findings from 'reflecting-on-practice' through this research enquiry, which suggest that a single network diagram is insufficient for accommodating the required information types and their complicated interrelations. This apparent mismatch between the graphic strategy and the nature of the biological content may lead to ambiguity about the nature and role of included elements, and illogical linking sequences. This finding reflects the conclusions from a group of scientists investigating ambiguities in ecological cycle diagrams at higher scientific levels (Le Novère *et al,* 2009).

Based on the analytical claims put forward in this thesis, I present three recommendations for an alternative information transformation rationale. These recommendations are aimed at each decision level in information transformation; they are centred on integrating information design expertise into current practice:

- Address the effectiveness of individual graphic tactics through considering related graphic syntax principles (Engelhardt, 2002). To support this a checklist is here provided summarising each of the 29 ineffective graphic tactics identified in this enquiry, in relation to effects on the content proper message, interrelated graphic tactics, and general guidelines for improving the effectiveness.

- Explore alternative graphic strategy of complementary diagrams, applying graphic syntax theory to analyse the source content and decide the features to represent.
- Integrate an information transformer role (Neurath and Kinross, 2008; Macdonald-Ross and Waller, 2000) into current practice to provide graphic syntax expertise and a systematic overview of the diagram design.

In relation to these recommendations the major contribution from this thesis lies in bridging the theoretical and professional practice context. This reveals firstly, the complicated interrelations between individual decisions in information transformation; secondly the direct link between decisions at each level of decision-making in information transformation and ambiguities in ecological cycle network diagrams as a case of visual output. Thereby this thesis provides further evidence for the necessity of an alternative information transformation rationale aimed at all three levels of decision-making, as outlined through the recommendations. Furthermore this contribution sets the ground for several future research explorations.

8.5 Future research

This research enquiry demonstrates a method for a systematic 'meta-reflection–on–practice' (Cherry, 2005; Schön, 2006). Such reflection in turn allows for setting information transformation design problems with greater awareness of potential theoretical and practical difficulties. When seen in a problem setting context (Schön, 2006) this thesis represents a preliminary information transformation stage, from generating research data to recommending a potential alternative information transformation rationale. This sets the ground for several future theoretical and practical explorations.

8.5.1 Graphic syntax theory

The development of the coding scheme for the visual content analysis in this enquiry contributes several insights to verbal syntax as a graphic syntax aspect. This conjunction of the visual and verbal language offers interesting opportunities for further investigation. One path would be to uncover greater detail about the nature of verbal syntax in relation to creating information categories. Such exploration may start at the grammatical features analysed in this thesis – linear verbal linking, verb phrases, and prepositions [appendix 7] – and identify the nature of different grammatical compositions in linking diagrams as well as other types of graphic representation. Another path could be taken through an instructional science approach, *ie,* investigating how different verbal syntax patterns affect the reader's processing and understanding of the diagram.

The bridging of theory and practice in this thesis also contributes knowledge to future development of information design theory, by revealing the external features that may affect the decision-making when generating visuals. Future work may focus on the dissemination of theoretical research, particularly the terminological aspect. Although disagreement on basic terminology may enrich an academic debate; it may simultaneously work against the practical application of the theory, thereby creating a gap between theory and practice. Within the current information design field, the theoretically biased language of some models may be an obstacle for disseminating to the practical field. In addition to the terminology, the potential channels of communication to specialist professional audiences could be investigated to facilitate a stronger bridge between the theoretical and practical contexts. In the context of this research enquiry such channels may be direct communication to educational publishers, or indirect channels such as educational or biological scientific journals. Such dissemination would aim at informing the exploration of alternative graphic strategies.

8.5.2 Alternative graphic strategies

Two of the recommendations put forward in this thesis offer promising ground for further exploration. A practice-led approach with a design management focus might investigate how to implement an information transformer role in the various practical settings found within educational publishing. A different path follows a practice-based approach, *ie,* applying 'the working practices intrinsic to the studio or workshop as a method in the structured process of research and in some cases perhaps as the methodology' (Evans, 2000, here from Dixon, 2001: 3·17). This thesis lays the foundation for a practice-based approach through the suggestions put forward as part of the recommended alternative graphic strategy [section 7.4.3, p. 332]. Future research may thereby explore different options for complementary diagrams for ecological cycles, led by graphic syntax theory. A user-centred approach may here be applied, offering the additional opportunity for further exploring phenomenography within an information design context.

A phenomenographic study offers a systematic method for investigating variation in how pupils experience the concept of ecological cycles. Variation theory here offers additional detail on the structural aspects of the different experiences (Pang 2003; Marton and Pong 2005). The findings of such study may thereby inform decisions about which features of an ecological cycle to present in complementary diagrams. As part of a practice-based research enquiry, this empirical method thereby offers a potential tool for providing an 'accountable and informed approach to communication' (Waller, 1979: 43). Hence such combination of research methods would potentially lead both the academic and practical field a step closer towards the general aims of information design. Such a step may also be taken by looking beyond the case of ecological cycle network diagrams and educational publishing, to the nature of information design problems in general.

8.5.3 Information design problems

This thesis has provided a foundation for developing descriptive and generalised models of information transformation processes, and the features that may affect the practice. Such further investigation might focus on the ill-defined nature of different types of information design problems. For example, mapping interrelations between graphic tactics and the involved trade-offs in relation to effectiveness. This would aim at identifying how the ill-defined nature of an information design problem may be reduced through different graphic strategies and tactics. Such research would inform further development of information design theory and provide essential knowledge for practitioners. Furthermore, the knowledge about internal and external factors that affect the information transformation process could here provide crucial evidence for highlighting the need for information design expertise in a design process, when generating this type of visual output.

Summary

This concluding chapter outlined how this thesis has met the original research aims and provided leads for future investigations.

The findings from analysing the visual content in relation to graphic syntax theory led to three claims about the visual output in its theoretical context. Firstly that an ecological cycle network diagram is an ill-defined problem; secondly, that ineffective graphic tactics occur in visual output in both the UK and Denmark, and, thirdly, that ineffective graphic tactics might lead to ambiguity about the ecological cycle message.

Based on the investigation of the professional practice context it was claimed that 'knowing-in-action' (Schön, 2006) dominates the current information transformation rationale. This reliance on tactic knowledge is led by largely inevitable solutions informed by the curriculum purpose of the visual output.

The integration of the research findings led me to claim that a direct relation exists between the identified information transformation rationale and ambiguities in the visual output. Furthermore I claimed that the current rationale is mismatched with an ill-defined design problem, due to the level of complication between graphic syntax aspects, biological content and the required trade-offs. Based on the analytical claims a set of recommendations were put forward to form an alternative information transformation rationale.

Different paths of future research were outlined for developing graphic syntax theory, exploring alternative graphic strategies, and furthering knowledge about the nature of information design problems. All these paths, like this thesis, are aimed at furthering information design theory and practice.

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Glossary

Artwork brief

A standard template specifying the position and layout of the visual, style, textual content, font, size, and caption heading. May also include a sketch of the diagram or visual references [section 2.5.2.1]

Brief development process

The process of developing an artwork brief for an ecological cycle network diagram [section 2.4.4].

Categories of description

Refers to the findings of a phenomenographic data analysis. The 'categories of description' identified by this research enquiry are the features attended to, and the variation in approaches described at each choice point in the brief development and translation processes [section 6.1.1.1].

Category of information

A nominal, ordinal or quantitative grouping of graphic objects created within a diagram. Hence groupings of the represented content proper. Nominal refers to categorising information by visual association or disassociation; ordinal to creating a visual hierarchy, and quantitative to creating visual groups based on related numerical information (Bertin, 1983) [section 4.3.1].

Choice point

A point in the process at which a design decision is made, ie a problem or sub-problem is paired with a potential solution or sub-solution (Schön, 2006; Dorst and Cross, 2001) [section 2.4.3].

Coding scheme

The defined units of analysis in a visual content analysis, organised as coding variables and sub-set of coding values [section 3.2.5].

Coding value

A sub-set of the smallest units of analysis within a coding variable. Defined as part of a coding scheme for visual content analysis [section 3.2.5].

Coding variable

A general unit of analysis defined as part of a coding scheme for visual content analysis. Comprises a sub-set of coding values which are the smallest units of analysis within a coding variable [section 3.2.5].

Co-evolution of problem-solution spaces

The process of considering and selecting potential solutions for a problem or sub-problems, ie deciding problem-solution pairings (Dorst and Cross, 2001) [section 2.4.2.2].

Content proper

The intended message of the diagram, *ie,* 'what is meant' with the graphic syntax [section 1.2.2.1].

Design constraint

A feature in the design situation that affects the design decision-making. See also external or internal design constraints (Lawson, 2006) [section 2.4.3.1].

Design functions

Different functions of an ecological cycle network diagram enabled through the design. Here refers to biological accuracy, aesthetics, and the balance between the two in relation to the reader (Dumas and Mintzberg, 1991) [section 2.4.5.1].

Design problem

The visual composition challenge facing a designer as part of information transformation, *ie,* information categorisation in an ecological cycle network diagram [2.4.3].

Design situation

A combination of a design problem and the situational context in which it is solved (Dorst, 1997) [section 2.4.3].

Design task

Solving an ill-defined design problem within a design situation in a given time (Dorst, 1997) [section 2.4.2.2].

Ecological cycle

A biological concept with in which elements with different biological nature, eg, organisms, processes, and matter interrelate through the continuous recycling of matter [section 2.1.2].

Ecological cycle network diagram

A network diagram representing an ecological cycle. The node and connector syntactic roles here represent the fundamental relationship between biological concepts in the ecological cycles.

Educational publishing

Publishers specialising in producing learning material such as textbooks. Textbooks are distinct from popular science publications by being part of a series adhering to the national curriculum [section 2.5.1].

Energy and force [italicised]

Semantic definition of general information type in ecological cycle network diagrams. Energy fuelling proesses, eg solar energy [Section 4.4.1.1; appendix 4].

External design constraint

A feature in the design situation that affects the design decision-making. External constraints mainly originate from the situational context, *eg,* the constraints imposed on a diagram from its relation to other page elements, to the audience level, or curriculum purpose [section 2.4.3.1].

Graphic object

A single instance of a shape, text or pictorial element included in a network diagram.

Graphic strategy

A level of decision-making within information transformation. Referring to analysing the defined source content and deciding the diagram type. Synonymous with information transformation tactics [section 2.1.3.2].

Graphic syntax aspect

Here refers to the specific graphic relations between graphic objects forming the analytical focus of this thesis [section 1.2.2.3].

Graphic tactic

A level of decision-making within information transformation. A selection and organisation of graphic objects and graphic relations within a graphic syntax aspect to represent an information type and its interrelations [section 2.1.3.2].

Ill-defined design problem

Ill-defined problems have no set goal or prescribed procedures. They are unpredictable, have flexible objectives, several possible answers, complex and multiple contexts, and unknown criteria and constraints. To solve an ill-defined problem requires a flexible process which accommodates problem formulation and sub-formulation during the design process [section 2.4.2].

Ill-defined problem space

Ill-defined problem spaces reflect a parallel relationship between the problem and solution meaning that potential solutions are considered whilst setting the problem. May include a sub-dimension of sub-problem and sub–solution spaces (Cross 2000; Dorst and Cross, 2001) [section 2.4.2.2].

Implicit nodes

An indicator of graphic ineffectiveness. Implicit nodes occur when the physical shape or spatial positioning of arrows, in relation to other objects, suggest an implicit connecting element [4.3.2.2].

Imprecise nodes

An indicator of graphic ineffectiveness. Imprecise nodes are graphic objects placed in close spatial proximity to two different graphic objects. This may cause ambiguity about the syntactic role of the imprecise element whether the represented content proper element is connecting or connecting [4.3.2.2].

Inconsistency

An indicator of graphic ineffectiveness. Relates to the categories of information created through individual 'attribute-based relations' (Engelhardt, 2002). This indicator is similar to polysemy but has a narrower analytical focus, by analysing different attributes separately, to reveal the consistency with which it is applied [4.3.2.2].

Indicator of graphic ineffectiveness

An indicator of graphic ineffectiveness is here a theoretical measure for identifying *ineffective graphic tactics* within each graphic syntax aspect [section 4.3.2.2].

Ineffective graphic tactic

An instance of graphic composition where the information categorisation may result in ambiguity about the content proper [4.3.2.2].

Information categorisation

The sub-activity of analysing the defined source content, selecting graphic objects and organising the effective composition; a tactical level of *information transformation* [section 2.1.3].

Information design practice

The defining and planning of source information, and effective composition of graphic objects in relation to precision in communication [section 2.1.2]. Here synonymous with *information transformation.*

Information transformation

Defining and planning a source information, and the composition through analysing the defined source content, selecting graphic objects and organising the effective composition, when transforming mainly verbal information – manuscripts, but also visual references – into visual language [section 2.1.3]. Here synonymous with information design.

Information transformation rationale

The designer's reasoning when defining, planning, and composing a visual output. In the science textbook context this relates to transforming mainly verbal information –manuscripts, but also visual references – into visual language [section 2.1.3].

Information transformation strategy

A level of decision-making within information transformation. Includes the defining and planning a source information, for example, deciding to include visuals in the first place, and defining the biological content [section 2.1.3.1].

Information transformation tactics

A level of decision-making within information transformation. Includes the analysis of a defined source content and deciding the diagram type. Synonymous with *information categorisation* [section 2.1.3.1].

Information transformer

An graphic syntax-led information transformer represents information design expertise and practical skills, and has a general understanding of the content proper, exam specifications, audience-levels, pedagogical theory, and production capacities [7.4.4.1].

Information type

A content proper element represented in a diagram. See, *organisms, processes, matter, material, pool, process, energy and force* [section 1.2.1].

Internal design constraint

A feature in the design situation that affects the design decision-making. Internal constraints originate from within a diagram *ie,* the composition of graphic objects, graphic syntax, and interrelations between graphic tactics and the graphic strategy [section 2.4.3.1].

Interview guide

The list of questions used when conducting semi-structured interviews. The development of the guide includes formulation of the interview questions and their sequence [section 3.1.1.1].

Matter [italicised]

Semantic definition of general information type in ecological cycle network diagrams. Matter is in this thesis defined as elements described precisely by chemical notation or terminology, *ie,* 'CO_2' and 'carbon dioxide' [Section 4.4.1.1; appendix 4].

Material [italicised]

Semantic definition of general information type in ecological cycle network diagrams. A broader category of *matter* referring to large human made or natural masses of *matter, ie,* 'waste' or 'fossil fuel'. [Section 4.4.1.1; appendix 4].

'Meta-reflection-on-practice'

A research enquiry in which a practitioner stands back and observes a specific area within a field of practice. Here relates to looking across the field of educational publishing rather than a single publisher (Cherry, 2005; Schön, 2006): [section 3.1.2].

Models of design activities

Theoretical models outlining different ways of delegating responsibility in relation to design functions (Dumas and Mintzberg 1991)[section 2.4.5.1].

Network diagram

A set of nodes and visually directed connectors, in which two or more nodes are linked in an open or closed loop [section 4.3.1.1].

Organising principles

The features which the participants choose to attend to at each choice point, variation in their approaches and the reasoning guiding the decision [section 2.4.3.1].

Organisms [italicised]

Semantic definition of general information type in ecological cycle network diagrams. Organisms are living things, *eg,* microbes, plants, humans, and animals [Section 4.4.1.1; appendix 4]

Overall dimension

The overall level of the problem and solution spaces. Here refers to the graphic strategy, *ie,* the network diagram type and biological content (Cross, 2000) [section 6.2.2]

Participant

A general description of any person involved in the information transformation process, including teachers and pupil readers [section 2.4.5].

Phenomenography

An empirical research method. Phenomenography enables mapping of a phenomenon – here *information transformation* – through identifying and categorising variation in the interviewees' approaches to their practice. The analysis method enables identification of the features attended to, the approaches, and the reasoning guiding the decision making at each significant choice point [section 3.1.1]

Polysemy

An indicator of graphic ineffectiveness. Occurs when a single or a group of visually similar graphic objects represent more than one information type [section 4.3.2.2].

Pool [italicised]

Semantic definition of general information type in ecological cycle network diagrams. Large and continuous storages of matter, *eg,* 'sea'. [Section 4.4.1.1; appendix 4].

Practice-led research

A research enquiry in which a practicing designer investigates a design problem in its professional context [section 1.5.1].

Process [italicised]

Semantic definition of general information type in ecological cycle network diagrams. A biological or chemical process [Section 4.4.1.1; appendix 4].

Problem-solution pairing

Deciding on a potential solution for a problem or sub-problem during the co-evolution of problem-solution spaces (Dorst and Cross, 2001) [section 2.4.2.2].

Problem setting

Preliminary, divergent, design activity in the design process in which the design situation is explored (Schön, 2006) [section 2.4.2].

Semantic definition of information types

Definition of information types based on verbal descriptions in existing diagrams [section 4.3.2.3].

'Silent design'

Design decisions taken by people who are not formally acknowledged as designers (Gorb and Dumas, 1987) [section 2.4.5.1].

Situational context

The environment of individual publisher in which the design problem is solved (Dorst, 1997) [section 2.4.3].

Sub-dimension

The sub-level of the problem and solution spaces. In this thesis the sub-dimension refers to the six *graphic syntax aspects*, each with additional sets of sub–problems, *ie,* the *graphic tactics* (Cross, 2000) [section 6.2.2].

Trade-off

Choosing the advantages of one graphic tactic over another whilst considering the interrelations and complications of the solution [section 7.3.1].

Translation process

An *information transformation* sub-process of translating an artwork brief into a network diagram [section 2.1.3].

Visual content analysis

An empirical research method for visual analysis which enables systematic identification of units of analysis within large data sets [section 3.2].

Well-defined design problem

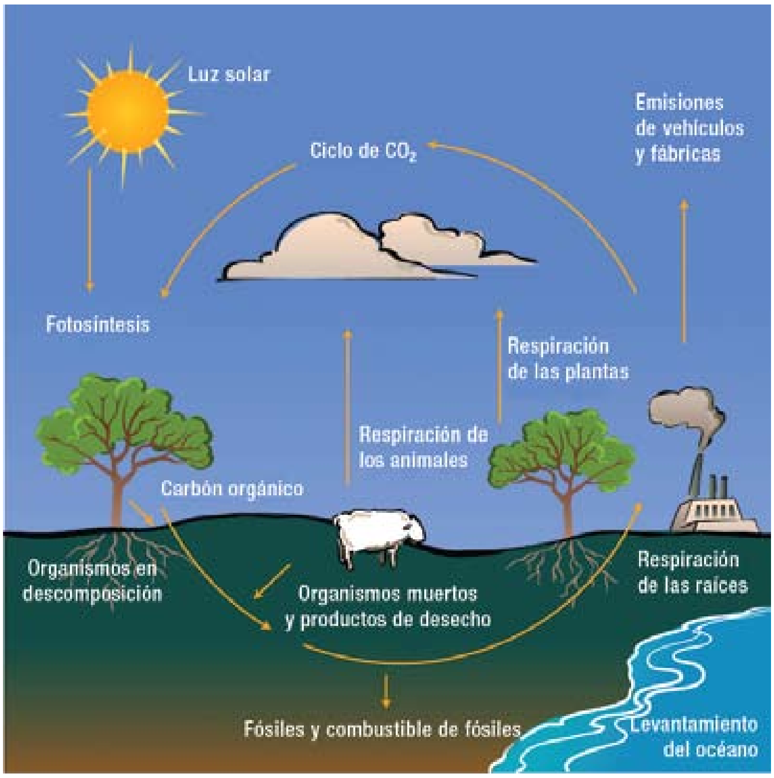
Design problems defined as analogous to scientific problems and seen as predictable. This and enables pre-analysis, setting of specific goals, and delegation of sub-problems to individual specialists [section 2.4.1].

Well-defined design problem space

A well-defined problem space is an illustration of the sets of sub-problems within a a well-defined problem, from which the solution may be synthesised. Often depicted using a tree diagram (Rowe, 1997) [section 2.4.2.1].

Appendix 1
Spanish diagram used for triangulation in interviews

This diagram was shown to the interviewees at the end of each interview [section 3.3.3.1]. A Spanish example was chosen to avoid Danish or English language preference. The diagram was shown and interview question 10 asked [see appendix 2]. Collecting the interviewees comments to the same visual example, enabled comparison of their critiques, and additional detail about their evaluation focus.



Available: **http://www.windows2universe.org/earth/Water/co2_cycle.html&lang=sp [10 September 2010].**

Appendix 2
Interview guide

This appendix documents the interview guide used for the 16 semi-structured interviews [section 3.3.3.1] conducted for this enquiry.

1 Demographic information

- Can you, briefly, describe your current job and its responsibilities.
- What's your background and experience - how did you get into this job?
- What was your role and responsibilities with textbook [title]
- What's your background and experience as an editor/author/designer/illustrator, how did you get into this job?
- How many years have you been an editor/author/designer/illustrator?

2 The double page spread

- What was your process for developing these pages?
  –how do you develop the text?
  –how did you develop the visuals?
- Can you sum up the main activities and their sequence?
- Who takes part in each activity?
- How would you sum up the role of each person?
- Does anyone take part informally, eg by commenting on the visuals?
- Who would you say has got the overall vision of the book, in relation to the content and to the visuals?
- How much work does each activity include, and what is the time scale of each one?
- What was your involvement with finding and choosing external designers? – agency/free lance/personal network/availability/previous work relation?

3 What is the format of the design brief?

- Written/verbal/both
- What is specified on the brief, what information do you give?
- How does the brief evolve, what is the process of defining the brief?
- Who takes part in defining the brief?

In the brief specifications how do you consider things such as

- How do you consider the relationship between text and visuals?
- How do you consider the layers of information in the diagram – how many different concepts are included?
- How do you consider typography – font/size/colour/positioning of text
- How do you consider the choice of background?
- How do you consider consistency between the different elements, for example:
  – size of pictorial objects?
  – positioning of similar elements (eg labels)?
  – colour coding?
- How do you evaluate the combination of all these elements into one structure?

4 What reference material is provided with the brief?

- Other titles by author/editor/designer/publisher
- Internet/Popular science books/Competitors books
- How does the reference material inform your work?
- How do you use existing diagrams for reference

5 If we look at the double page spread here, what is the purpose of each visual element (photos, graphs, diagrams)?

- Would you consider using just one type of visual? – Why/why not?
- Who do you discuss the intended purpose with?
- How do you consider the pupils and teachers when deciding on visuals?
- How do you anticipate this book being used by the teachers and pupils?
- Does the curriculum-level influence your choice of visuals?
- How does knowledge about learning and teaching influence the choice and purpose of the visuals?
- Do you use academic research about these themes?
  for example: published studies/journals/consult experts/conferences?
- How does knowledge about visual and design theory influence the choice and purpose of the visuals? –eg Gestalt theory
- Do you use academic research on these topics?
  for example: published studies/journals/consult experts/conferences?

6 If we focus on the diagram and look at the visual objects, within it.

- How do you consider the information applied to each type of object? – eg, what is applied to the arrows and what is shown pictorially?
- How do you consider the purpose of the pictorial objects/text objects/ arrows/the boxes?
- Does the blank background have a specific purpose, as opposed to a full pictorial illustration?
- When you specify a diagram like this in the brief, how do you consider these purposes ?
- How do you discuss these purposes with the other participants?

7 When you've got the first draft of a diagram, how do you evaluate it, what is your criteria?

- How do you look at things such as the layers of information in it?
- How do you evaluate the combination of pictures and text within the diagram?
- How do you evaluate the Typography? font/size/colour/positioning of text
- How do you evaluate the choice of background
- How do you evaluate the consistency between the different elements? – size of pictorial objects/positioning of similar elements (eg labels)/ colour coding?
- Who takes part in evaluating the firsts draft?

7a Questions for designer/illustrator only:

What is your process for designing a diagram, based on the brief?

- What are the main activities and their sequence?
- How do you develop your ideas?
- What sort of research do you do? – visual and biological references.
- How do you use existing diagrams?
- How do you do sketching?
- What is your main focus at each stage of the process?
- How do you evaluate the work in progress versions?
- What tools do you use?
- Who else takes part in the practical design process? – eg collegues

- What's the time frame for the design process of a diagram like this?

8 When you've got the final version of a diagram, how do you evaluate if it is successful?

- What's your criteria?
- Who takes part in evaluating the final diagram?
- Do you do any external evaluations?
  for example: users/teachers/experts/professional reviews/other reviews?
- What do you do if you think something can be a point for improvements in future diagrams?
- How would you compare the way you evaluate a diagram at the brief stage, the first draft stage and the final version?

9 If you were to reflect on your work process, what do you think works, and is there anything you'd like to change?

10 As a last thing, I would like to show you a spanish example of a diagram, If this was sent to you for use in a book, how would you evaluate the design of this diagram?

- How do you look at things such as the layers of information in it?
- How do you evaluate the combination of pictures and text within it?
- How do you evaluate the Typography? font/size/colour/positioning of text
- How do you evaluate the choice of background?
- How do you evaluate the consistency between the different elements?
  – size of pictorial objects/positioning of similar elements (eg labels)/ colour coding?
- How do you evaluate the combination of all these elements into one structure?
- Would you consider this a successful diagram?

Appendix 3
UK Data set
Diagram group 1: text and arrow.

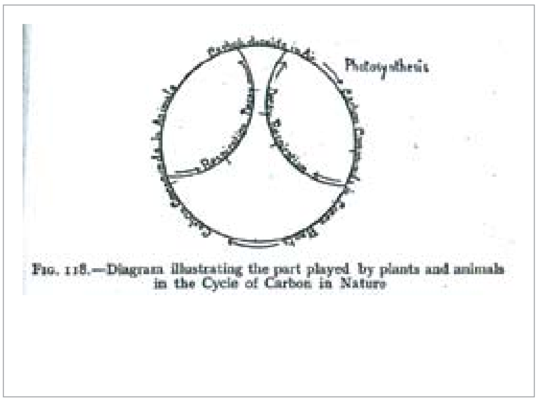


FIG. 118.—Diagram illustrating the part played by plants and animals in the Cycle of Carbon in Nature

1930Shove_R_CC

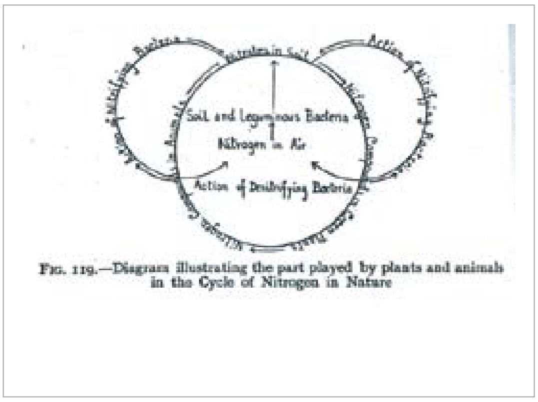
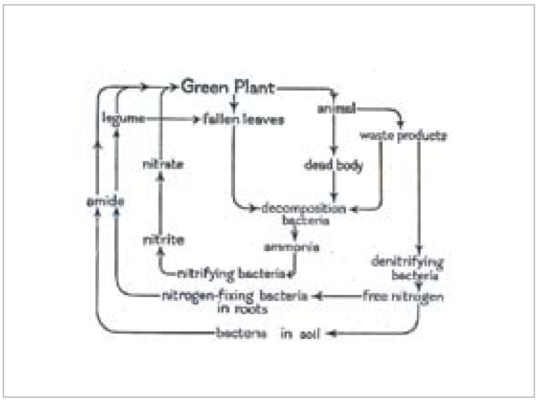


FIG. 119.—Diagram illustrating the part played by plants and animals in the Cycle of Nitrogen in Nature

1930Shove_R_NC



1935Spratt_E_NC

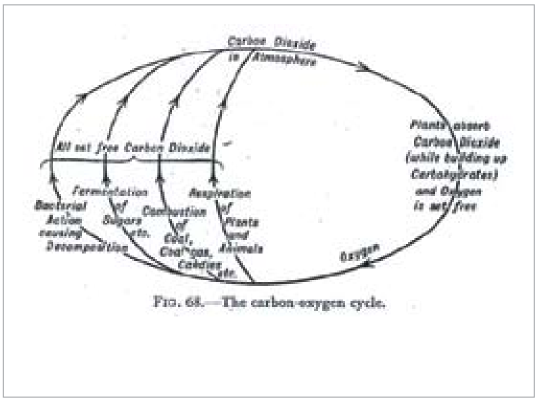


FIG. 68.—The carbon-oxygen cycle.

1936Hunter_J_CC

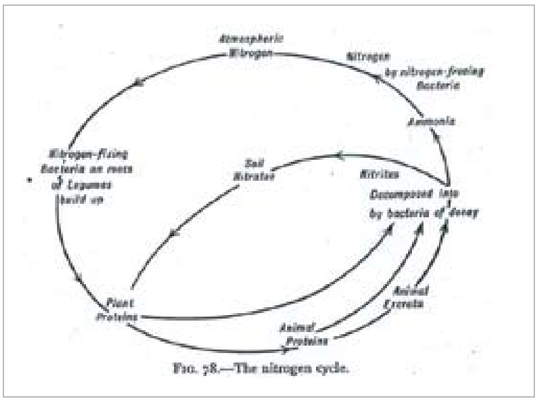


FIG. 78.—The nitrogen cycle.

1936Hunter_J_NC

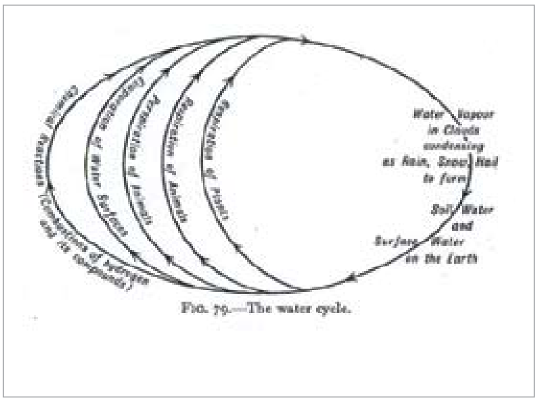
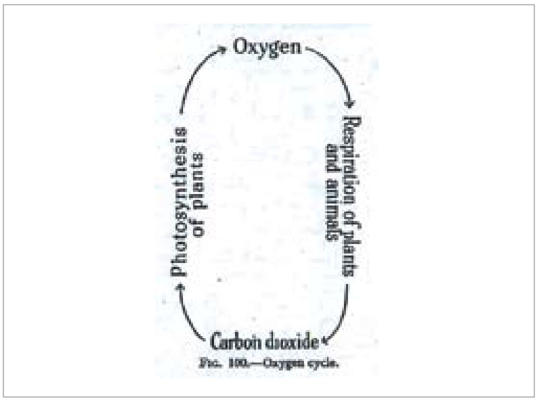
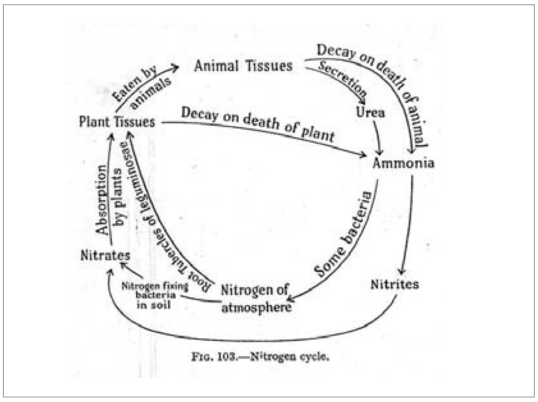


FIG. 79.—The water cycle.

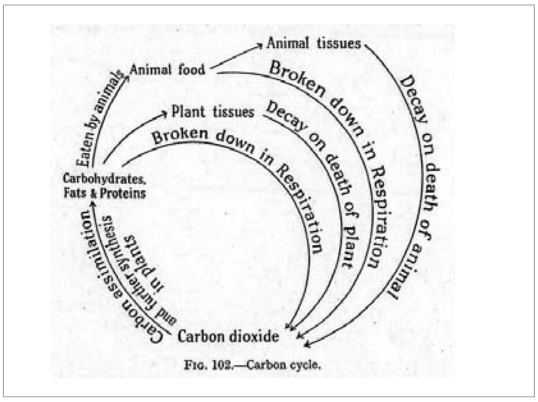
1936hunter_J_WC



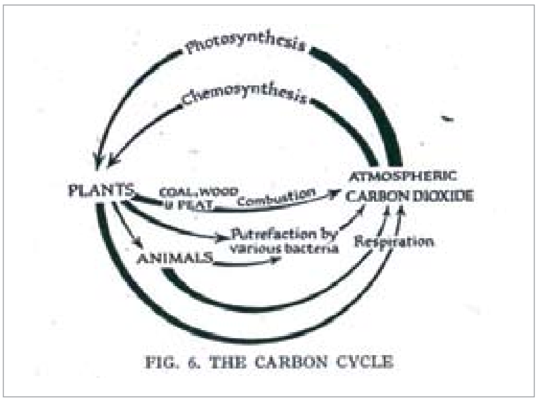
1936Phillips_M_CC



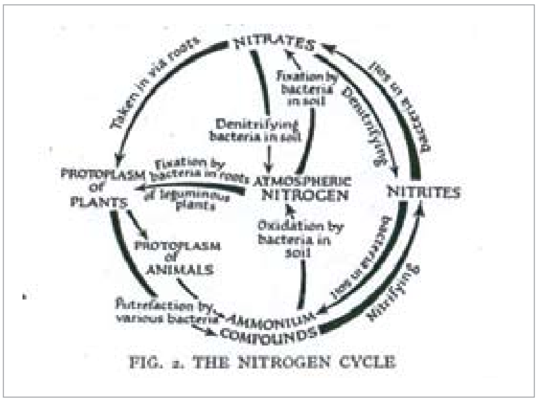
1936Phillips_M_NC



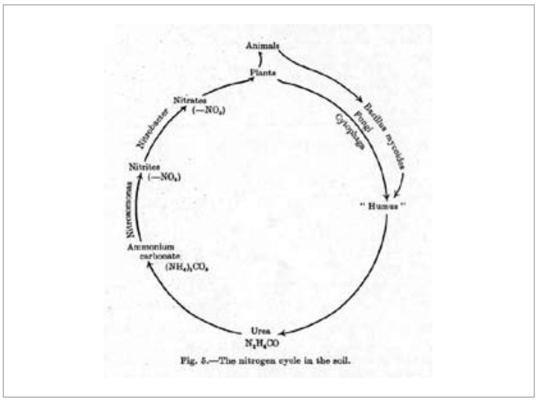
1936phillips_mCC



1937Graham_A_CC

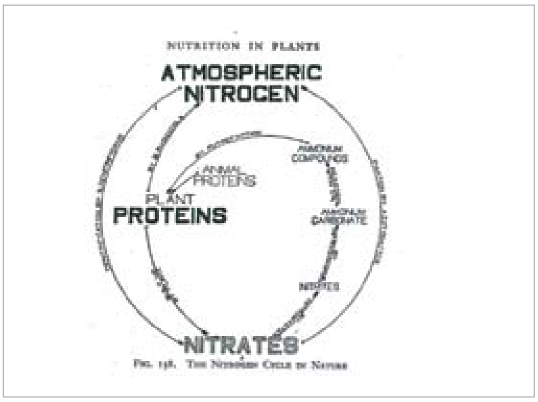


1937Graham_A_NC

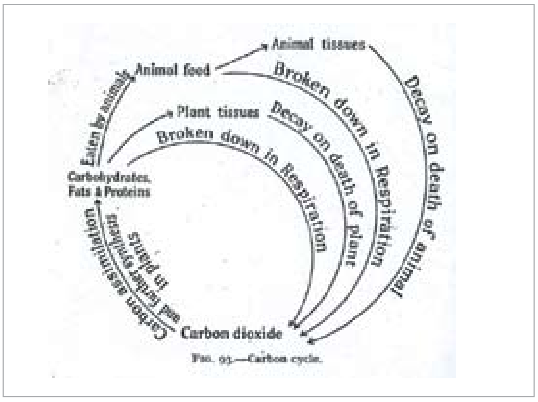


1937Wight_W_NC

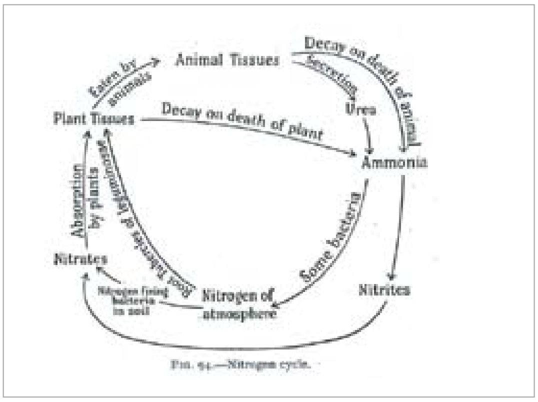
1939Brimble_I_CC



1939Brimble_I_NC

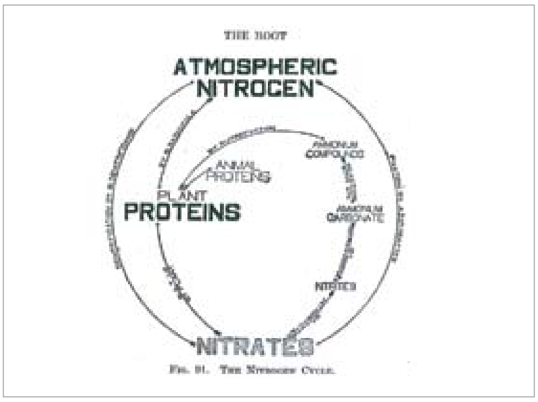


1940Phillips_M_CC

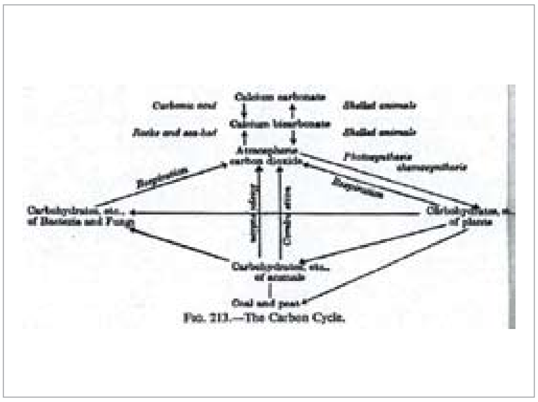


1940Phillips_M_NC

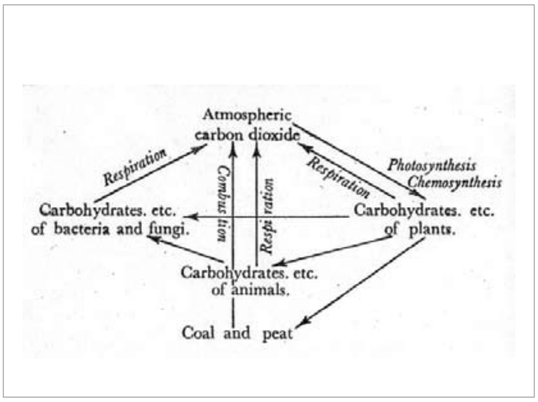
1946Brimble_I_CC



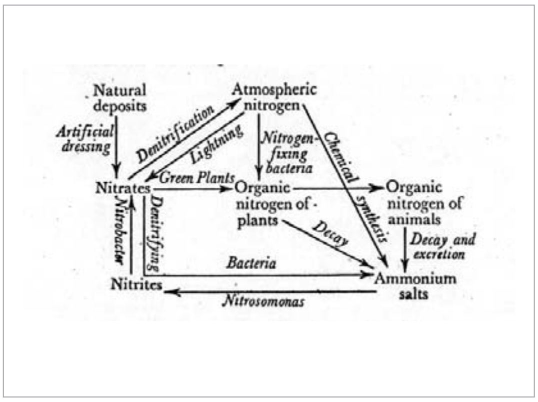
1946Brimble_I_NC



1946Wheeler_W_CC



1946Wheeler_W_CC1



1946Wheeler_W_NC

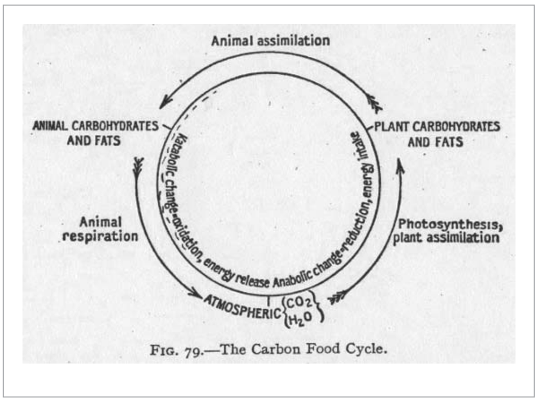
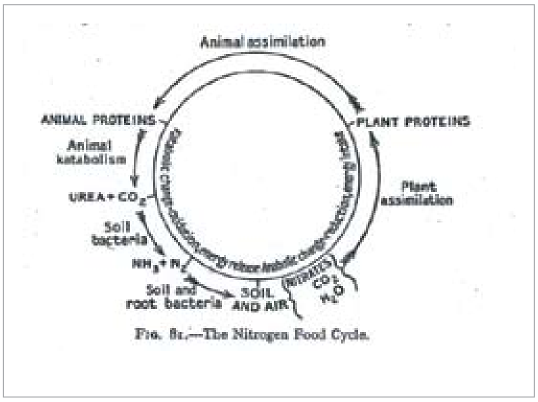
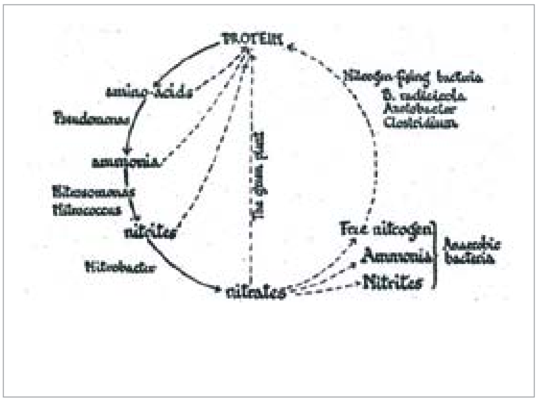


Fig. 79.—The Carbon Food Cycle.

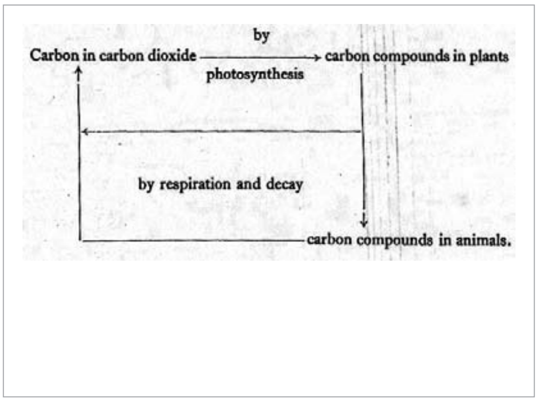
1947Read_J_CC



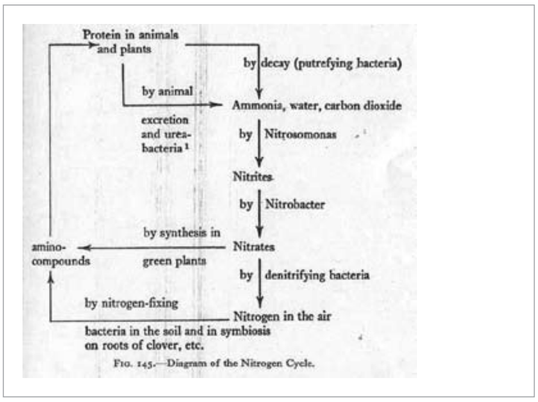
1947Read_J_NC



1948Godwin_H_NC



1949Cooke_H_CC



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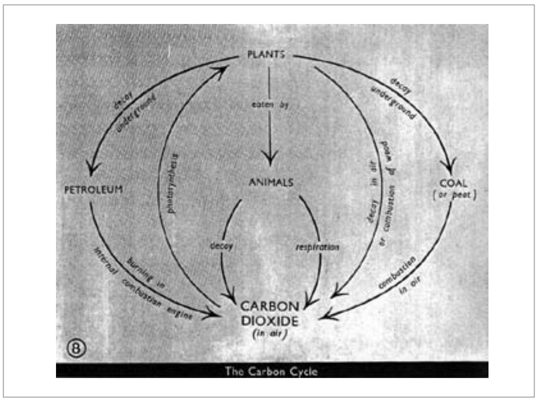
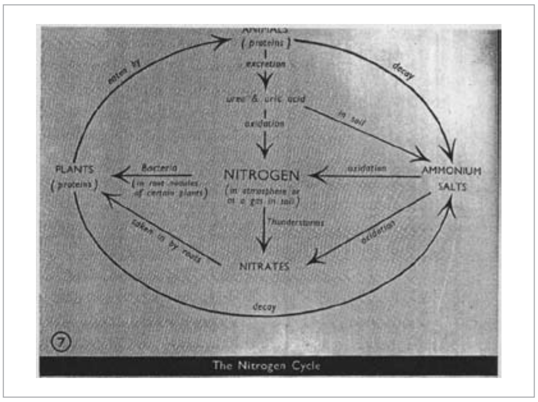
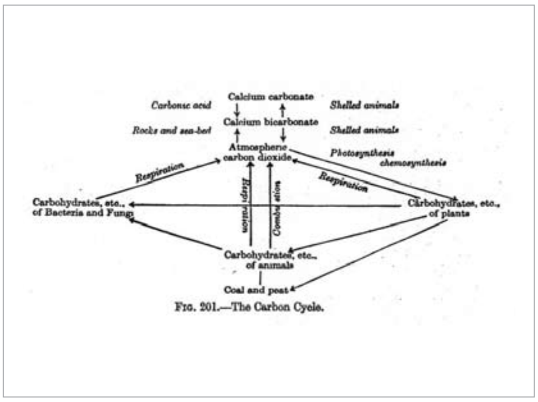


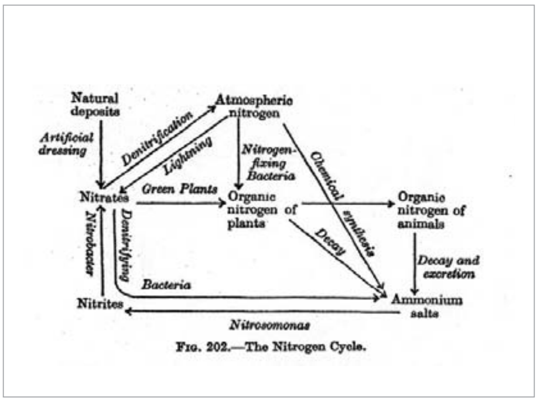
1949Wood_C_CC



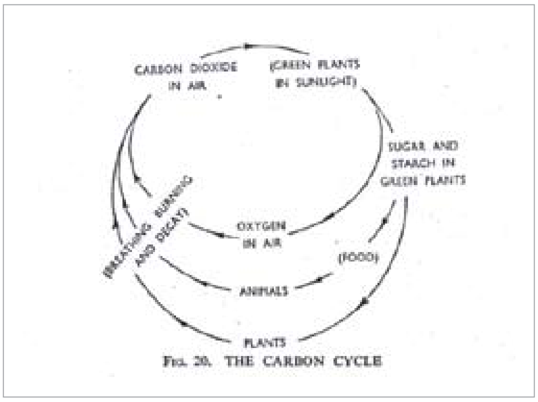
1949Wood_C_NC



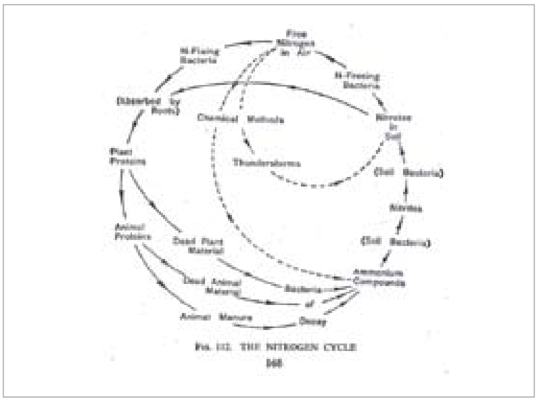
1951Wheeler_W_CC



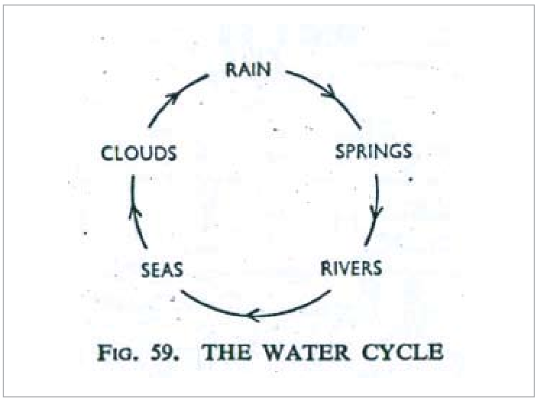
1951Wheeler_W_NC



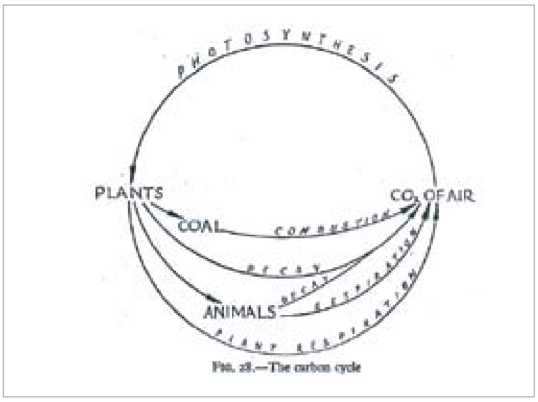
1954Daniel_F_CC



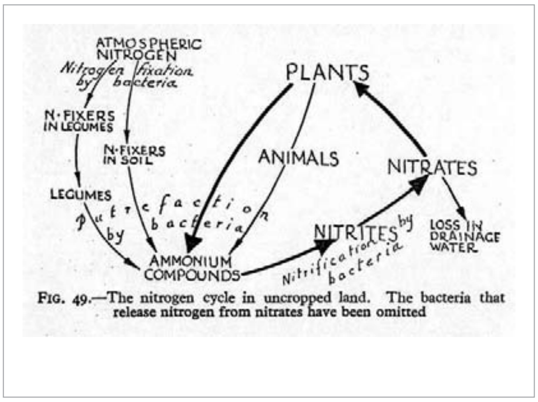
1954Daniel_F_NC



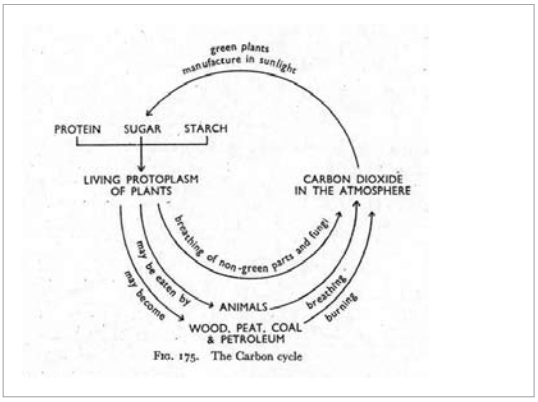
1954Daniel_F_WC1



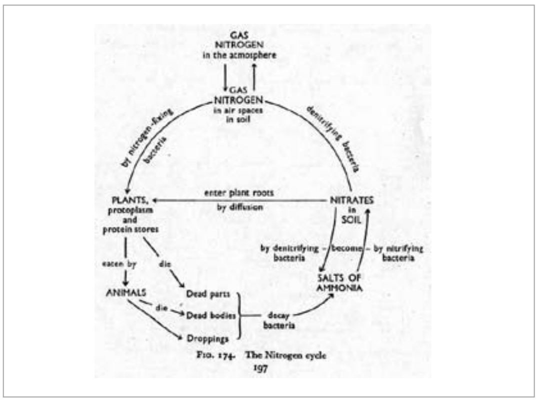
1954Palmer_R_CC



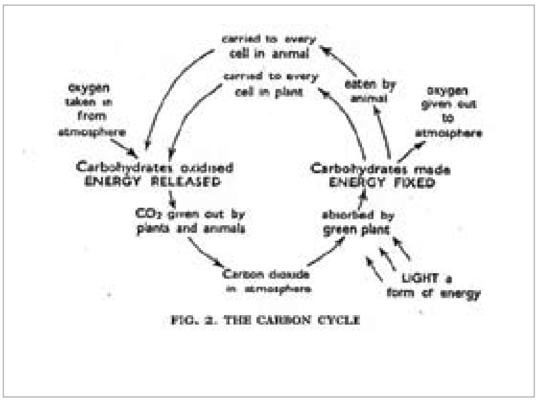
1954Palmer_R_NC



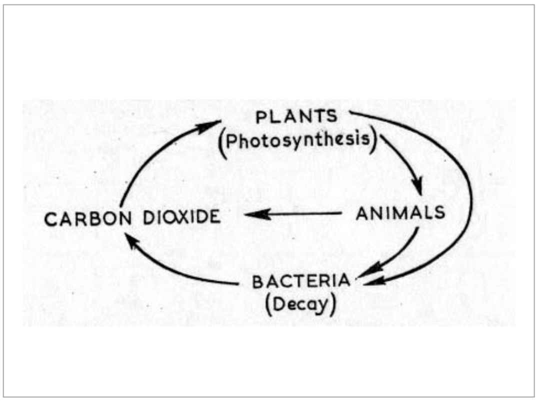
1956wilkinson_M_CC



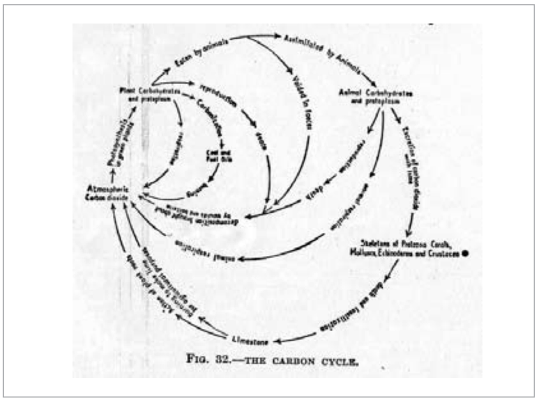
1956Wilkinson_M_NC



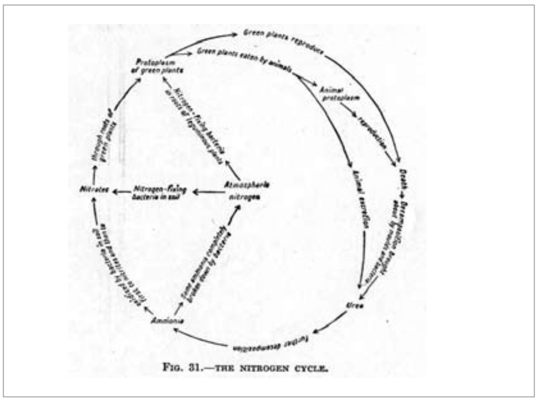
1957Allright_E_CC



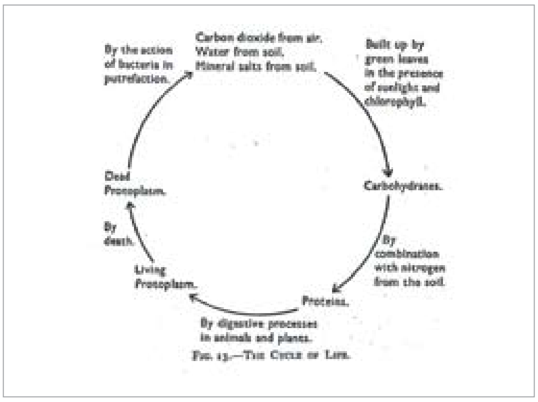
1957Saunders_E_CC



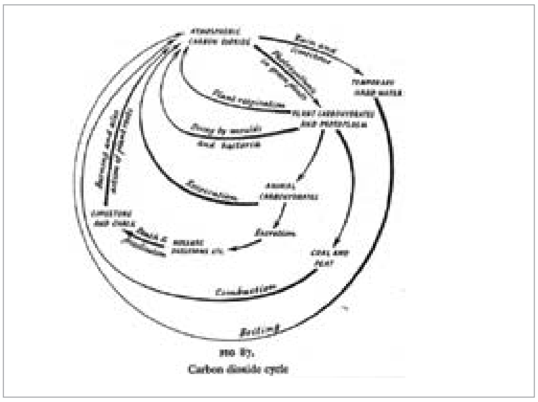
1958Stork_M_CC



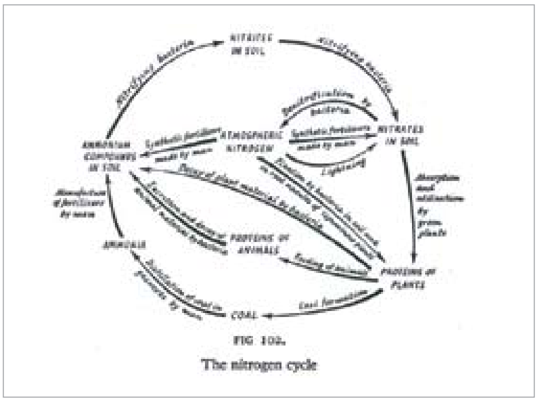
1958Stork_M_NC



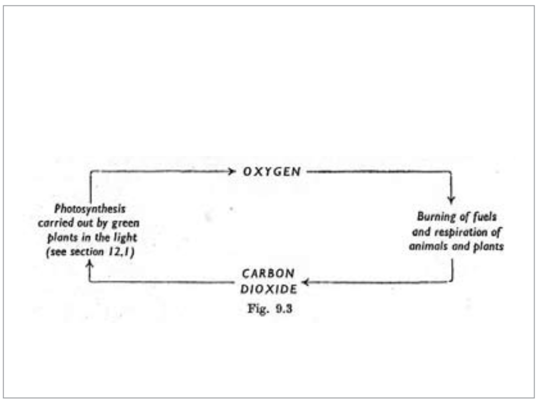
1959Goodwin_M_CC



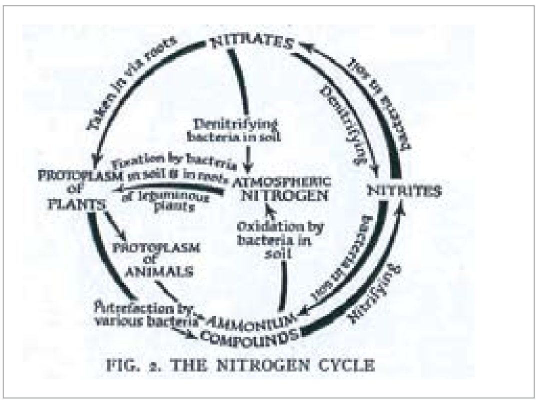
1960Brekhaut_D_CC



1960Brekhaut_D_NC



1962Brocklehurst_K_CC2



1962Graham_A_NC

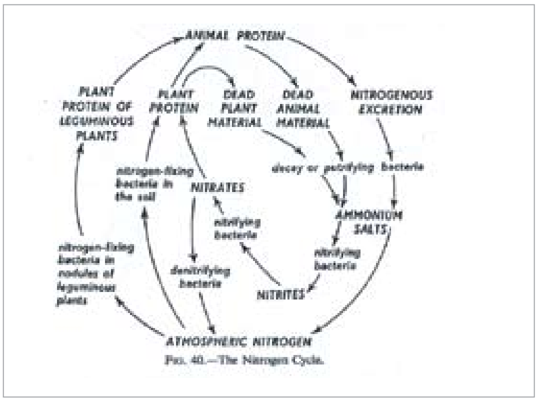
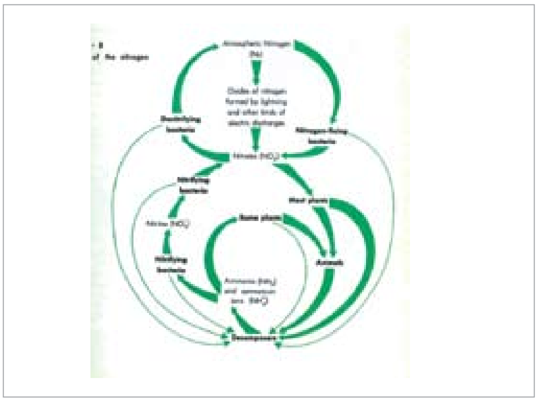


Fig. 40.—The Nitrogen Cycle.

1962Sparrow_K_NC



1963Kolb_H_NC

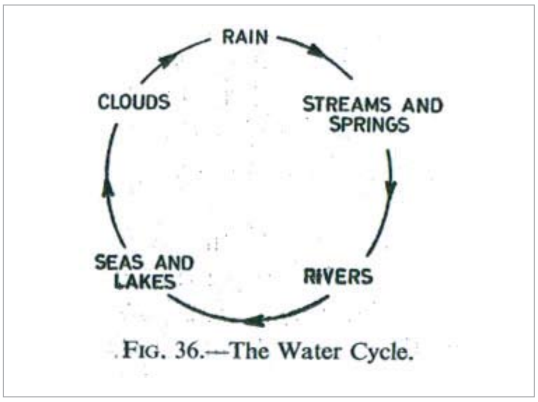


Fig. 36.—The Water Cycle.

1964Atkinson_A_WC

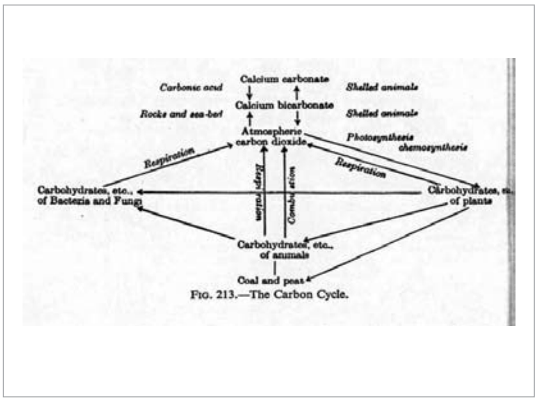


Fig. 213.—The Carbon Cycle.

1964Wheeler_W_CC

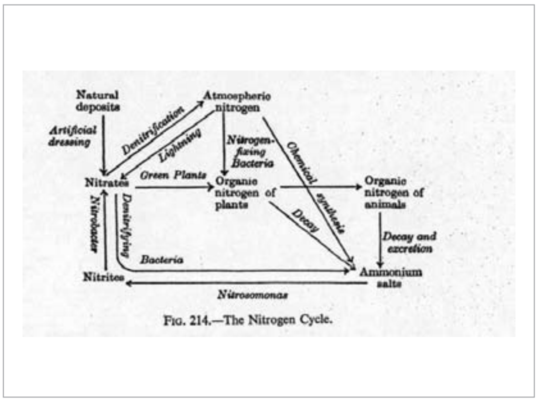
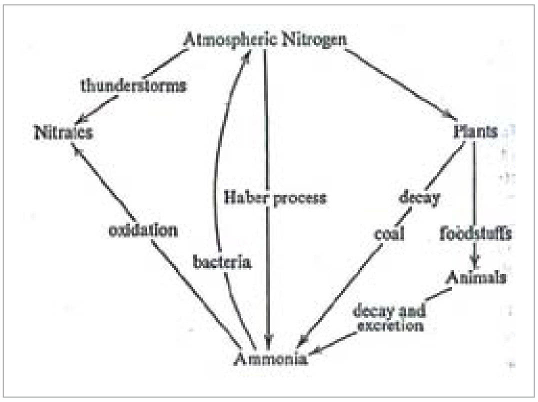


Fig. 214.—The Nitrogen Cycle.

1964Wheeler_W_NC



1965Cook_E_NC

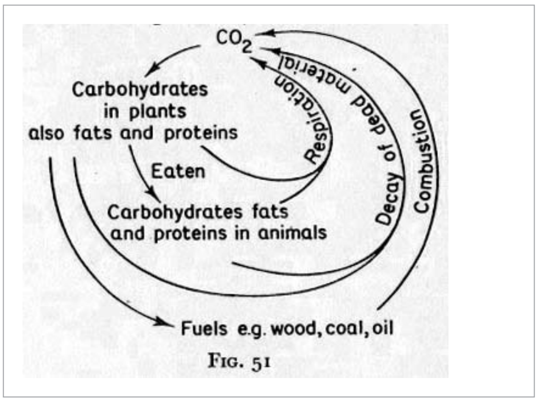


Fig. 51

1967Winckler_K_CC

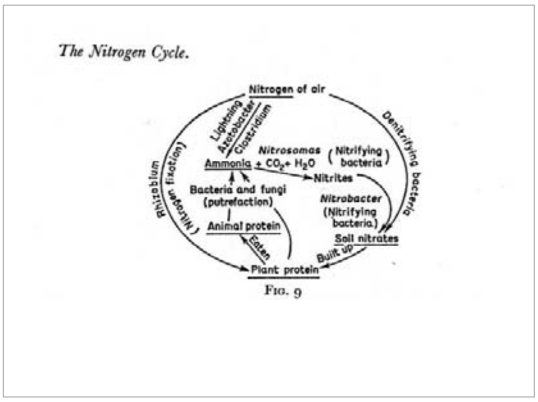
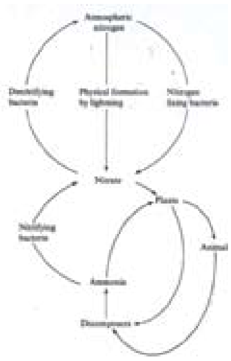
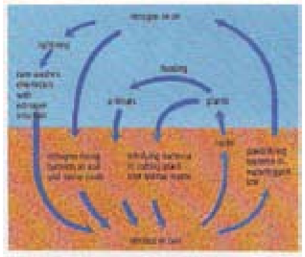


Fig. 9

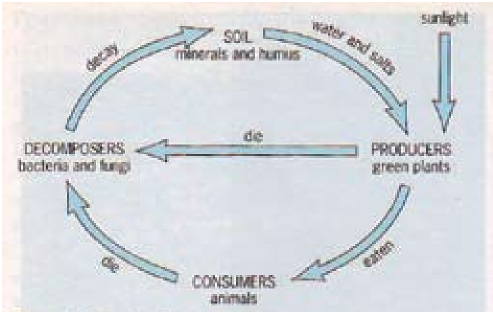
1967Winckler_K_NC



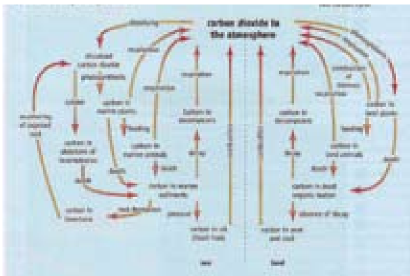
1972Ewer_D_NC



1994Taylor_C_NC.tif

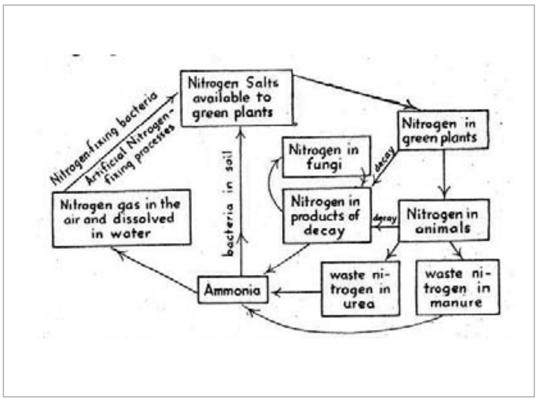


1995Mackean_d_CC

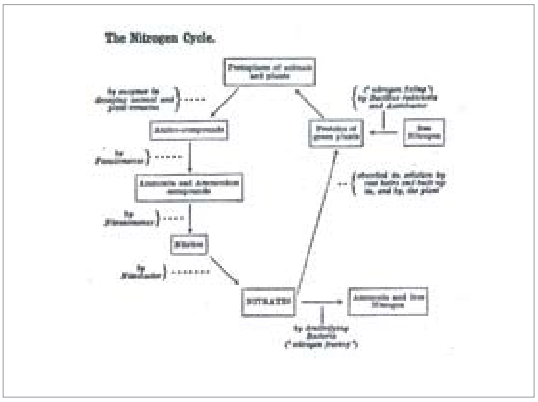


2005Salters_CC

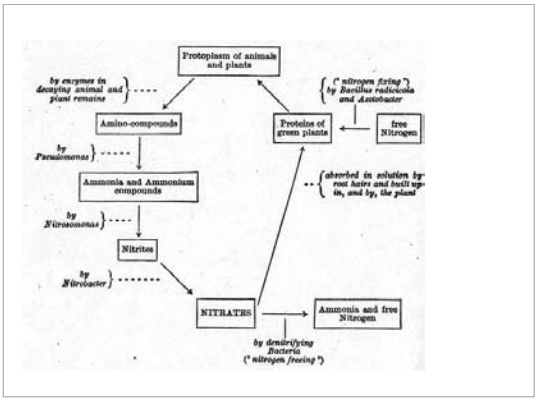
Appendix 3
UK Data set
Diagram group 2: text, arrow, and container.



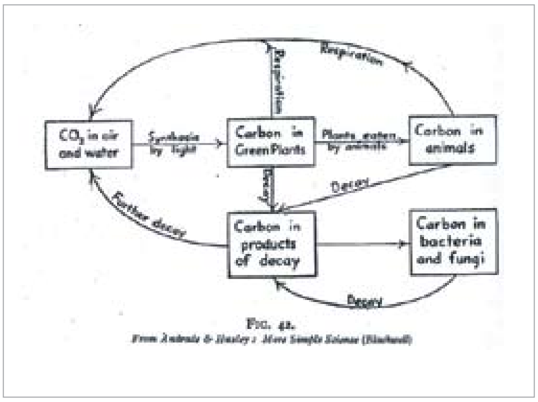
1935Andreade_A_NC



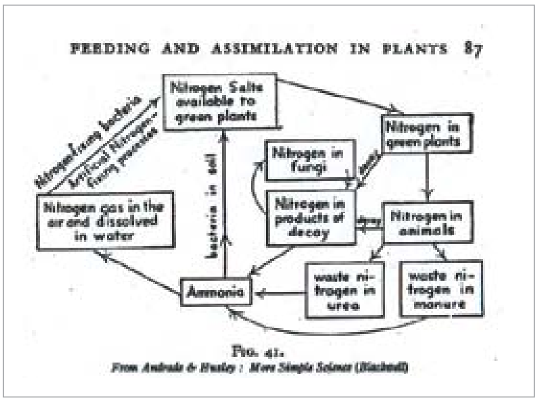
1935Wyeth_F_NC



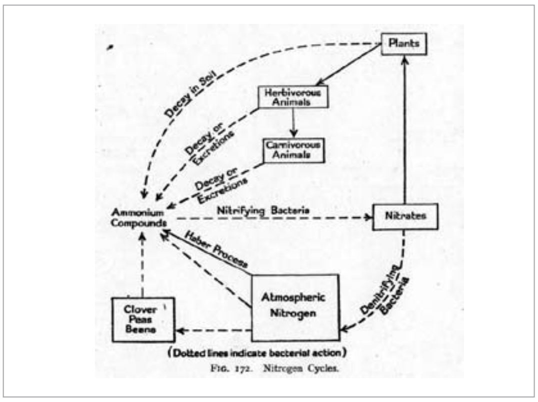
1937Wyeth_F_NC



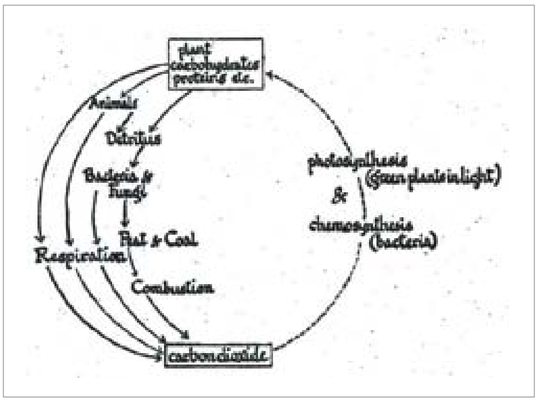
1939Munro_M_CC



1939Munro_M_NC



1939White_S_NC



1948Godwin_H_CC

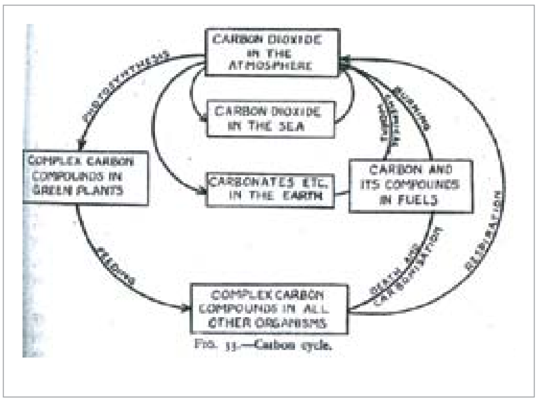


Fig. 53.—Carbon cycle.

1948Grogan_J_CC

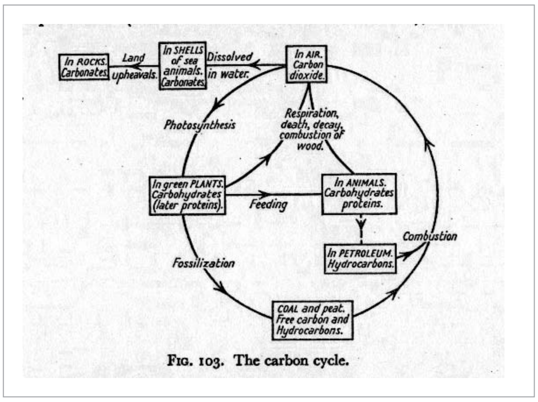
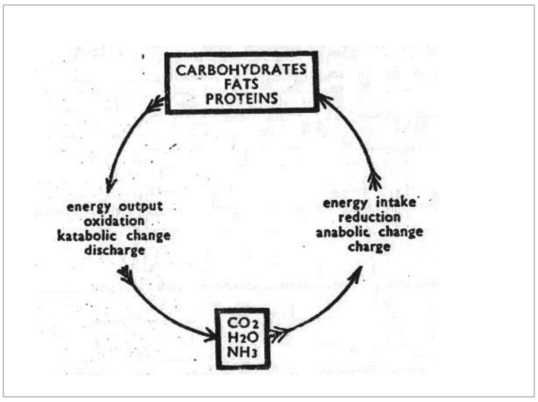


Fig. 103. The carbon cycle.

1948Whitehouse_S_CC



1949Read_J_EC

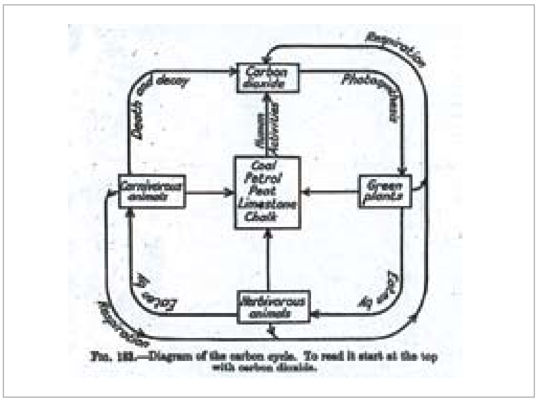


Fig. 183.—Diagram of the carbon cycle. To read it start at the top with carbon dioxide.

1955Dale_A_CC

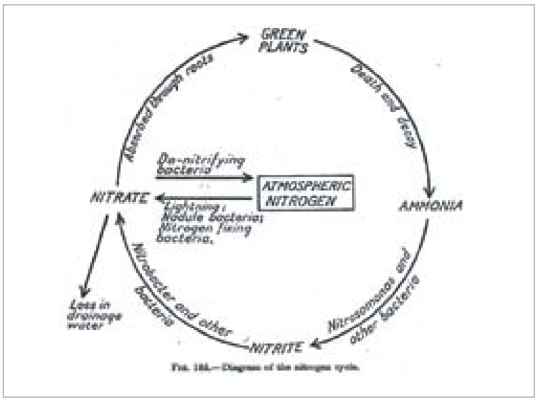


Fig. 184.—Diagram of the nitrogen cycle.

1955Dale_A_NC

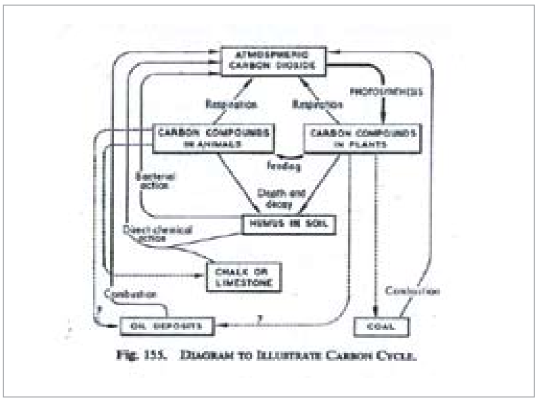


Fig. 155. Diagram to Illustrate Carbon Cycle.

1957Archer_E_CC

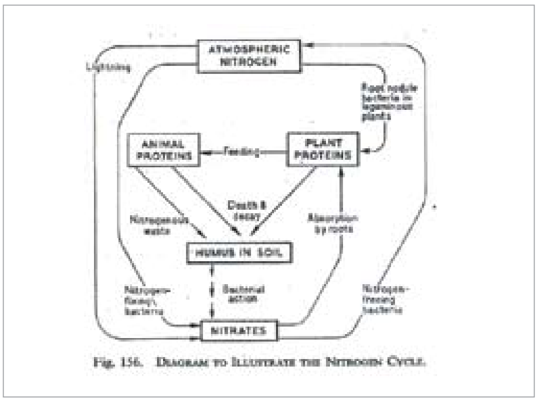
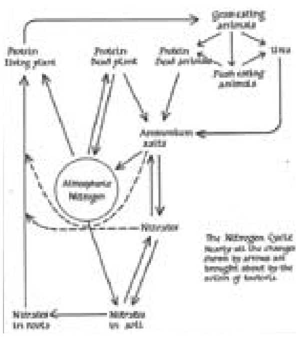


Fig. 156. Diagram to Illustrate the Nitrogen Cycle.

1957Archer_E_NC

1958Brocklehurst_K_CC



1958Reed_G_NC

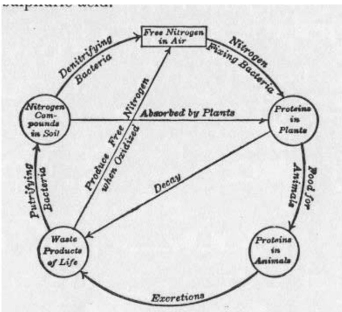


FIG. 338.
DIAGRAM OF THE NITROGEN CYCLE IN NATURE.

1960Parsons_I_NC

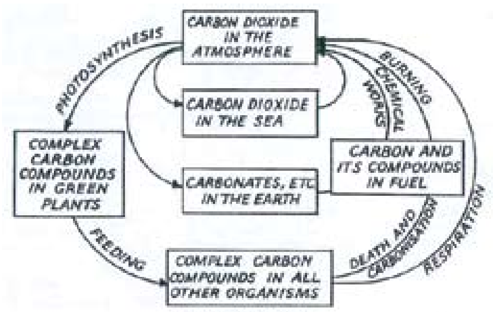
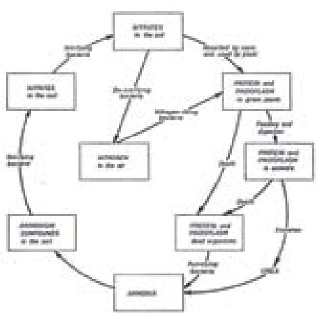
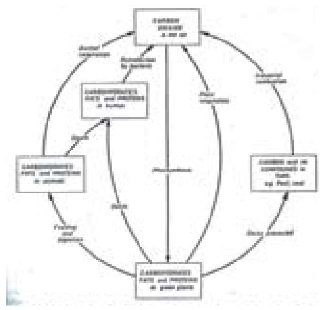


FIG. 26. Carbon cycle.

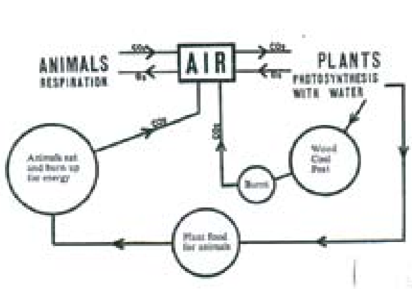
1961Grogan_J_CC



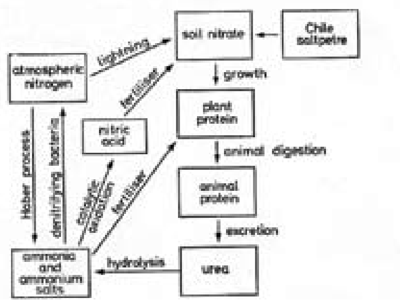
1962Brocklehurst_K_NC



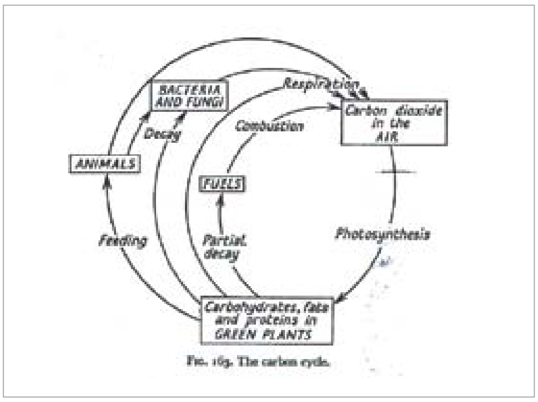
1962Brocklehurst_K



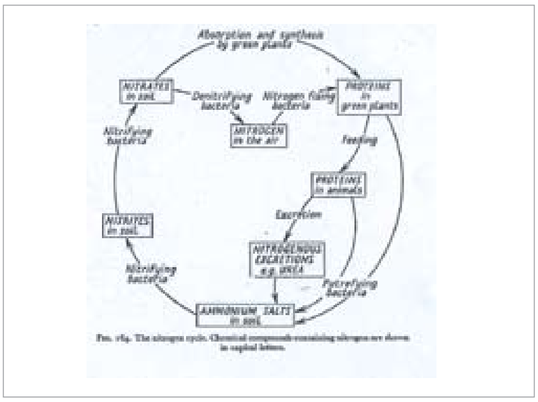
1962Knock_H_CC



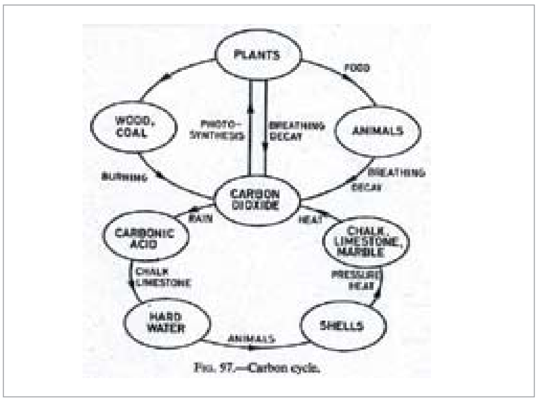
1963Aynsley_E_NC



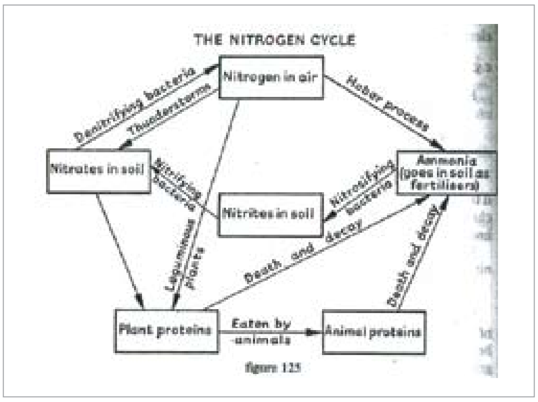
1963Hatfield_E_CC



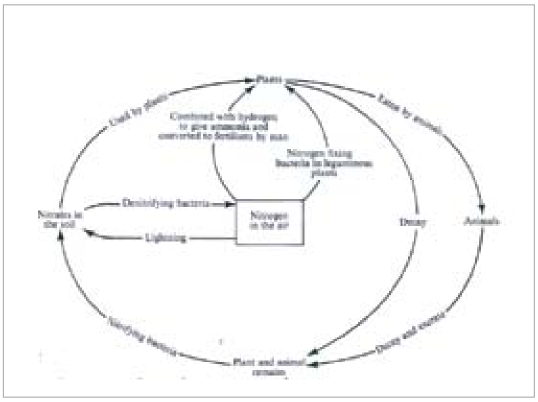
1963Hatfield_E_NC



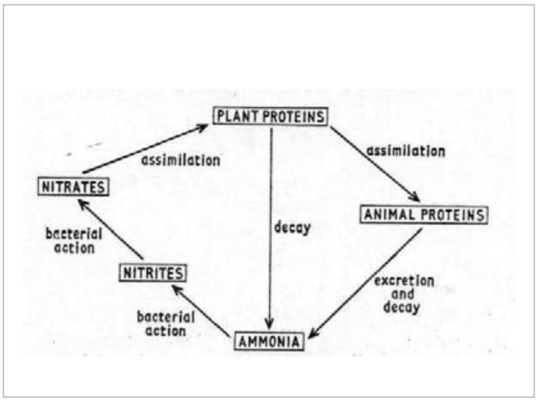
1964Atkinson_A_CC



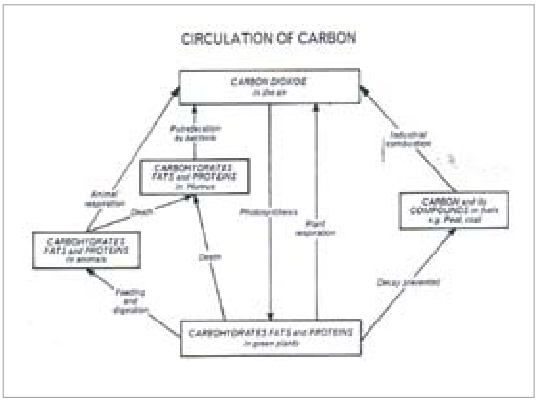
1965Abbott_D_NC



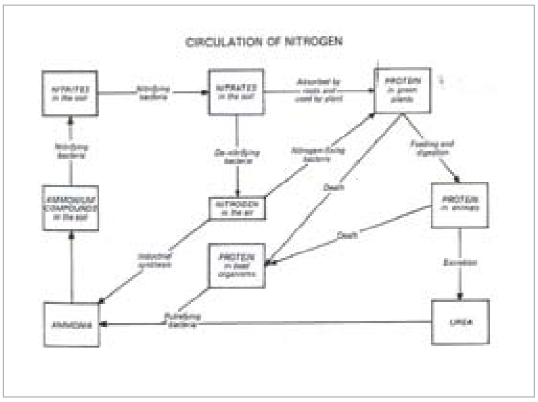
1965Chillingworth_D_NC



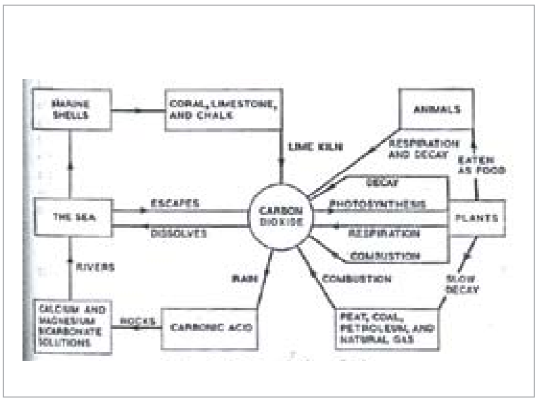
1967Vernon_F_NC



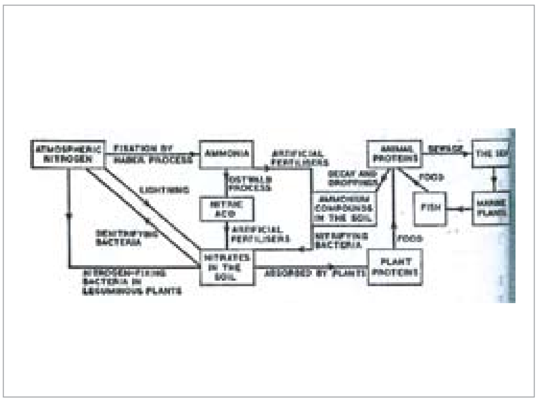
1968Brocklehurts_K_CC



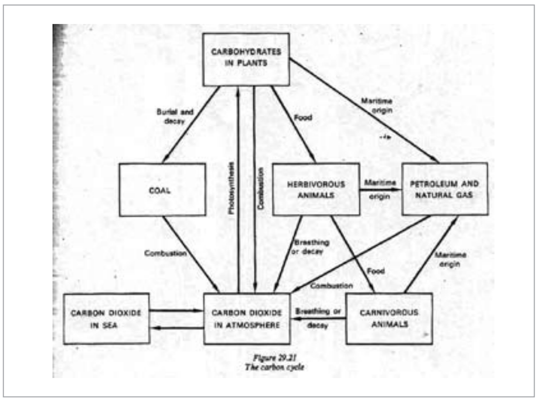
1968Brocklehurts_K_NC



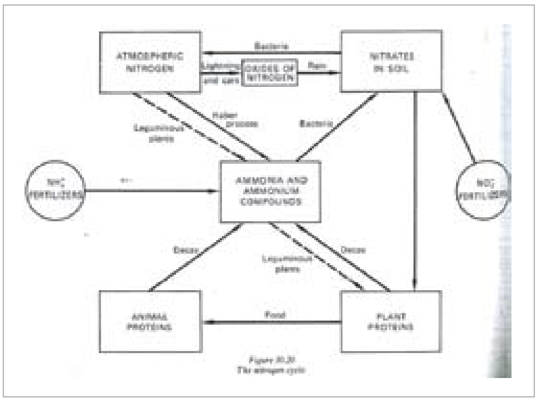
1970Hicks_J_CC



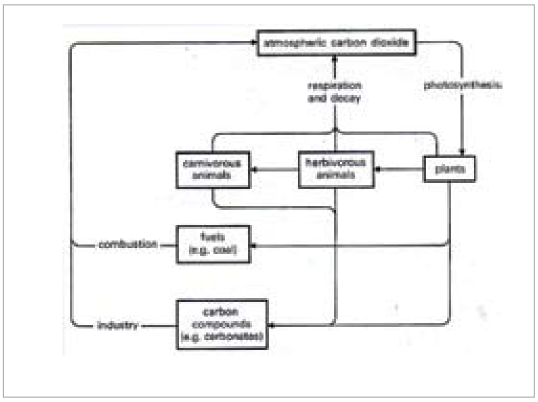
1970Hicks_J_NC



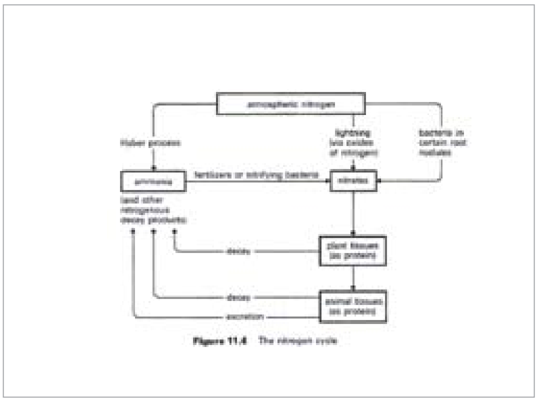
1972Clynes_S_CC



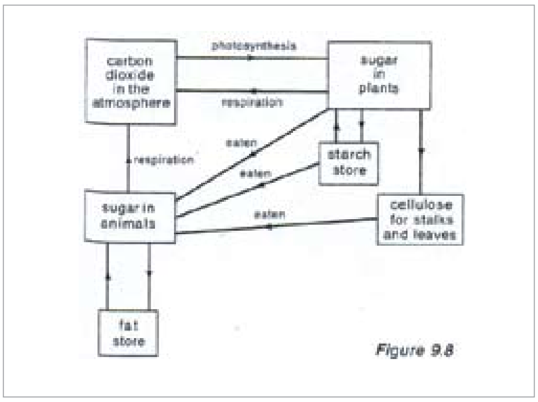
1972Clynes_S_NC



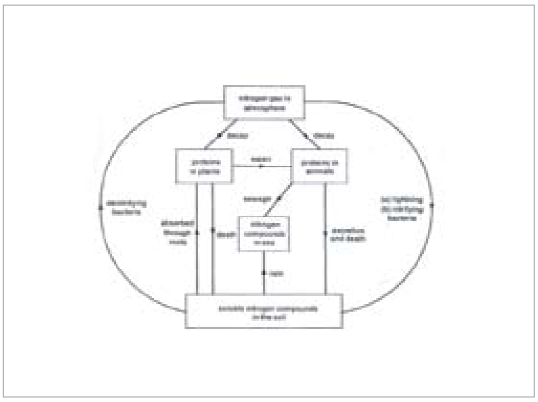
1973Davies_I_CC



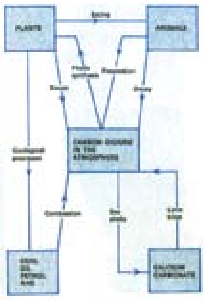
1973Davies_I_NC



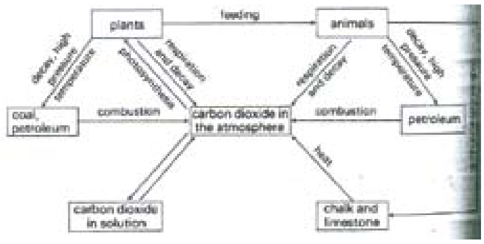
1976Henderson_E_CC



1976Henderson_E_NC



1977Cane_B_CC



1978Barker_A_CC

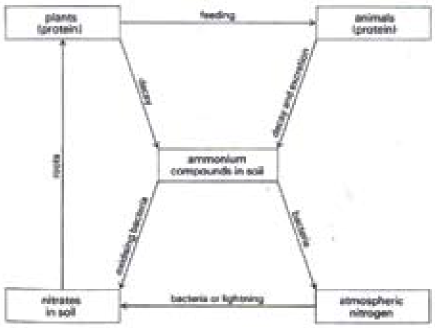
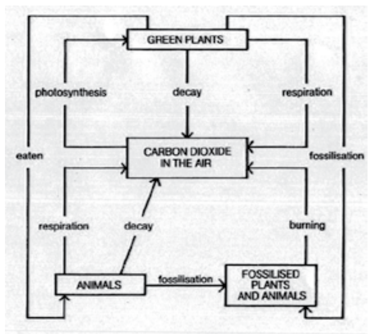


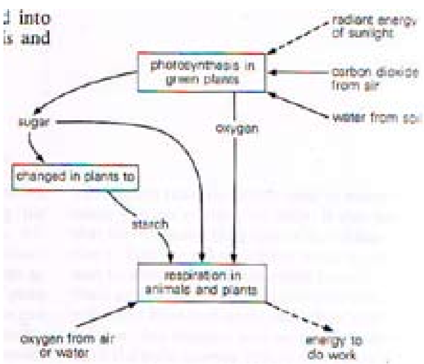
Figure 17.4.3 The nitrogen cycle

1978Barker_A_NC

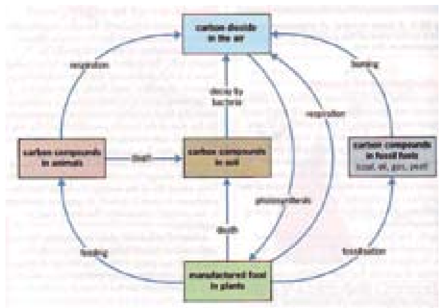


The carbon cycle.

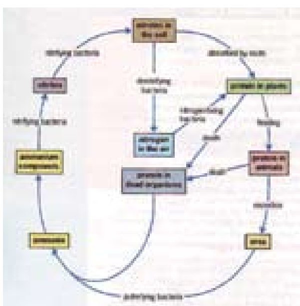
1979Bavage_A_CC



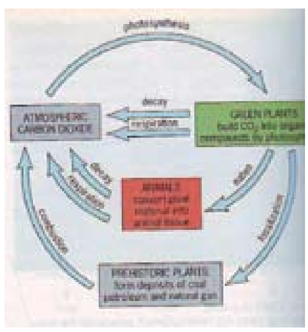
1982_Hogg_M_CC



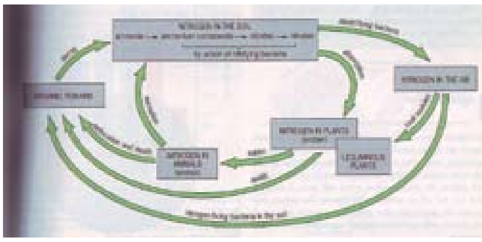
1994McDuell_B_CC



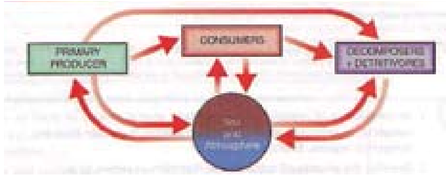
1994McDuell_B_NC



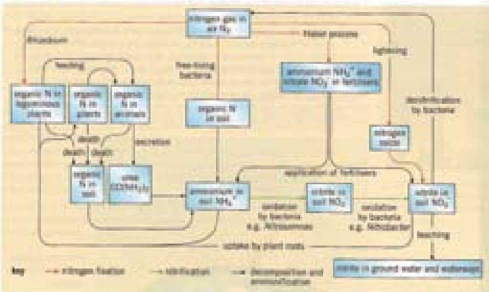
1995Mackean_D_CCa



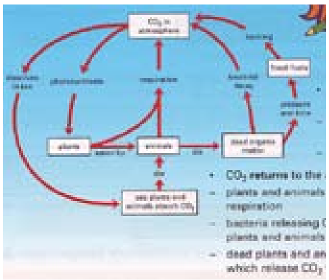
1995Mackean_D_NC



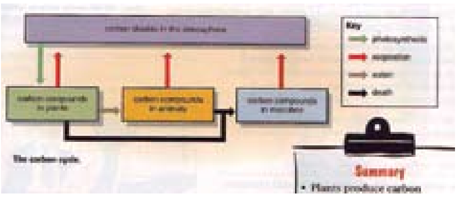
2000Lea_C_EC



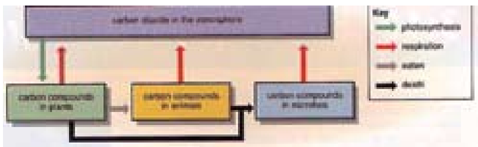
2001Graham_NC



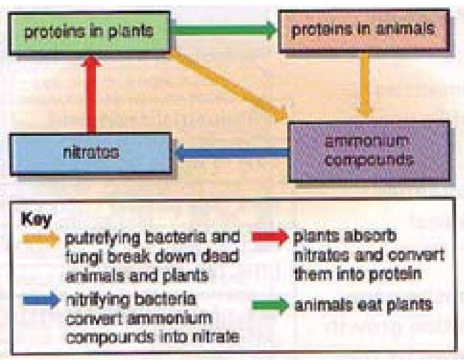
2002_Lees_D_CC



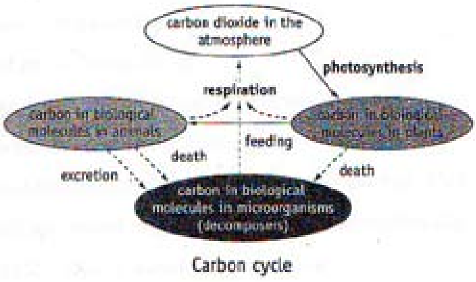
2002Hirst_K_CC



2002hirst_K_CC



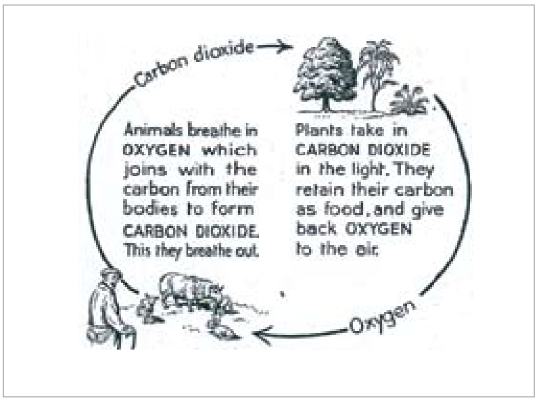
2002Hirst_K_NC



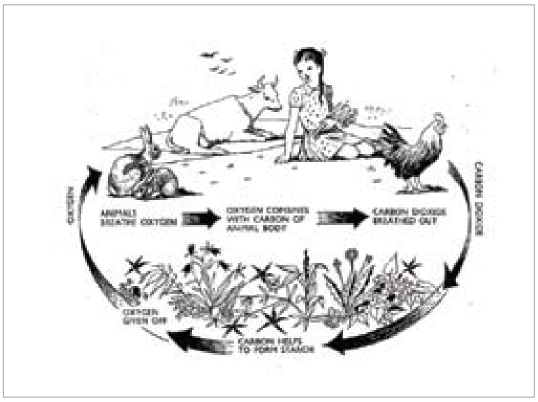
2003Read_G_CC

Appendix 3
UK Data set
Diagram group 3: text, arrow, and pictorial object.

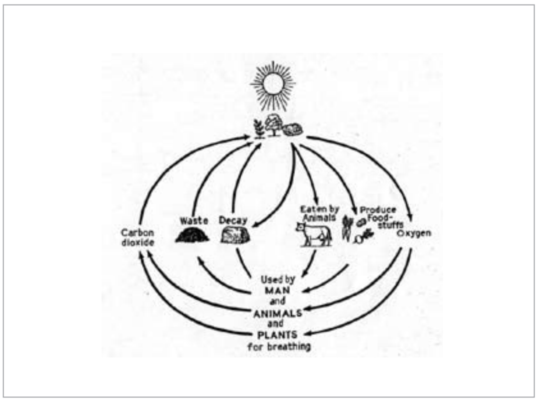
1937Spratt_E_NC



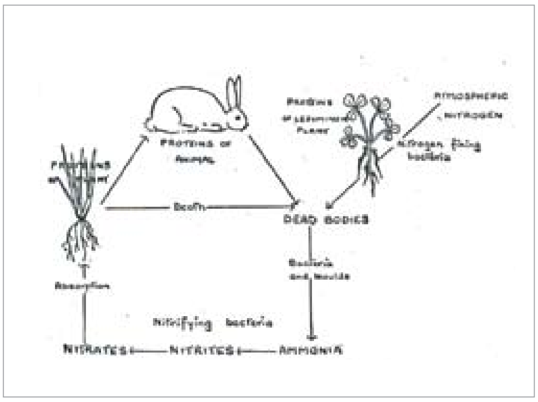
1952Webb_H_CC



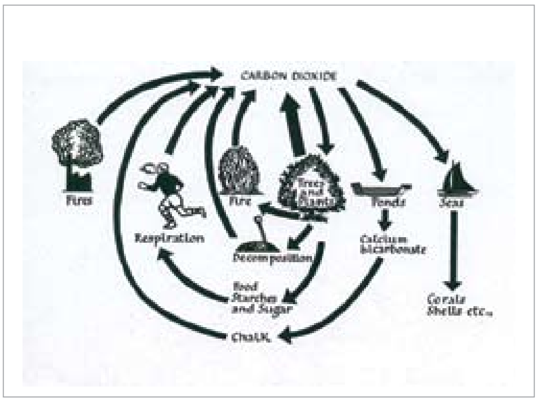
1953Allcott_A_CC



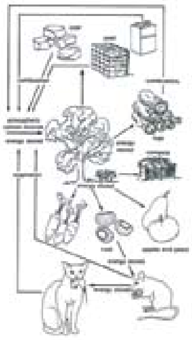
1954Tyrer_F_CC



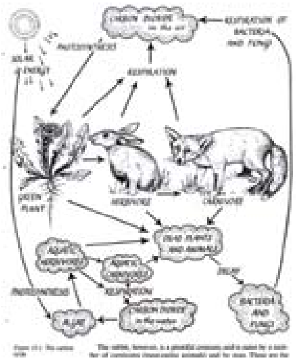
1957Green_M_NC



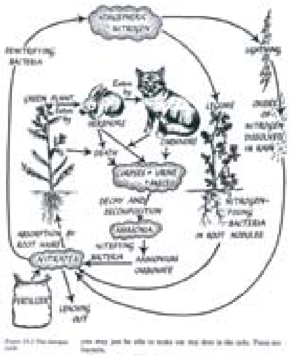
1958Reed_G_CC



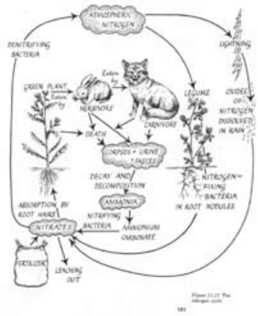
1971Marson_J_CC



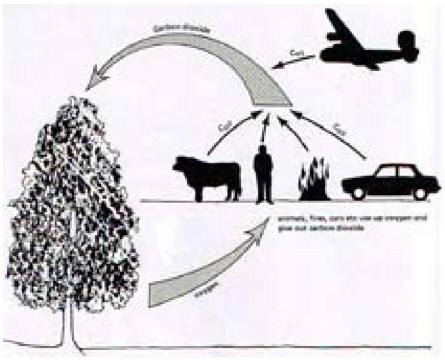
1972Ewington_E_CC



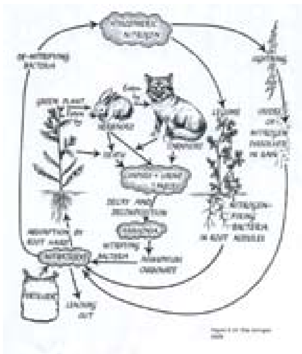
1972Ewington_E_NC



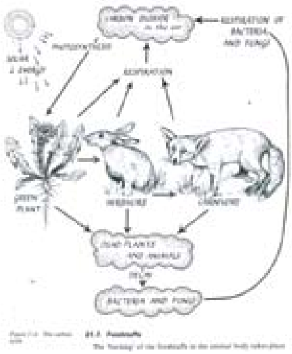
1972Savage_N_NC



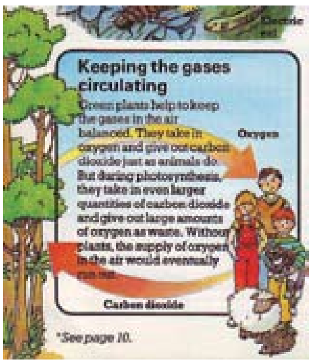
1977_Latchem_W_CC



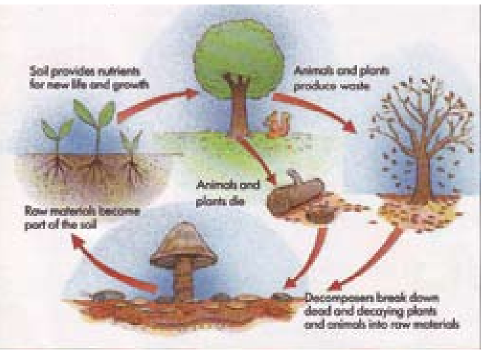
1978Campbell_J_NC



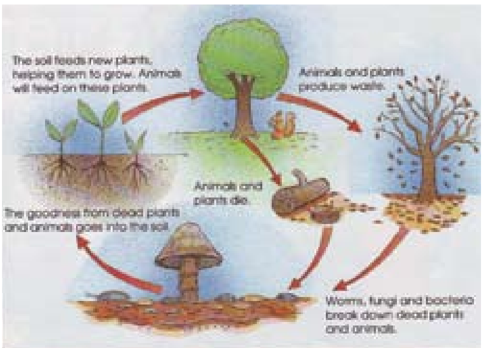
1978Stone_R_CC



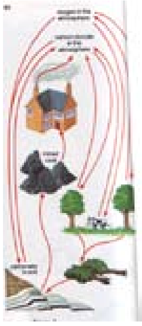
1984Chisholm_G_CC



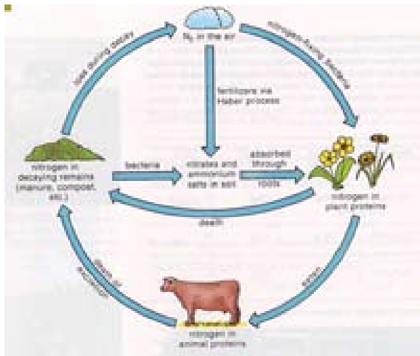
1989James_B_CC



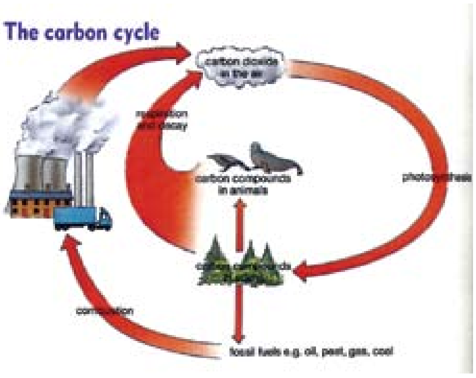
1991James_B_CC



1993Hill_G_CC

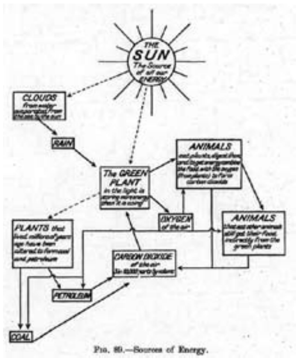


1993Hill_G_NC



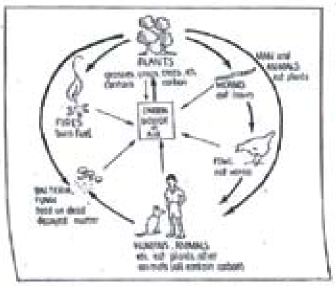
2001Sears_J_CC

Appendix 3
UK Data set
Diagram group 4: text, arrow, pictorial object, and container.

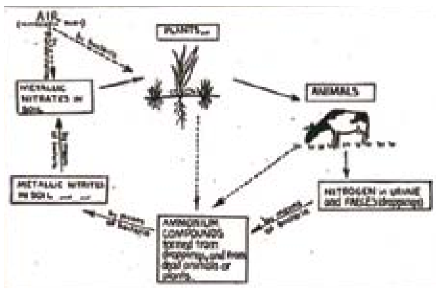


1937Bryant_J_CC

1937Spratt_E_CC



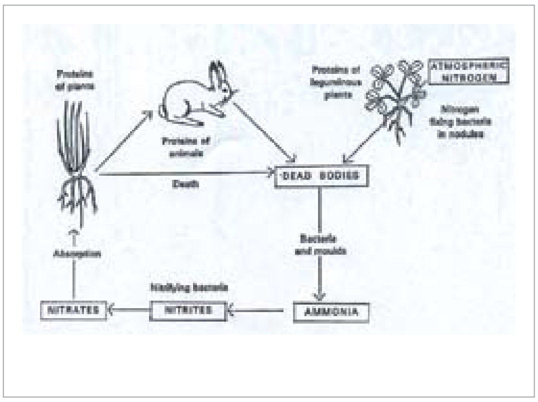
1948Pugh_S_CC



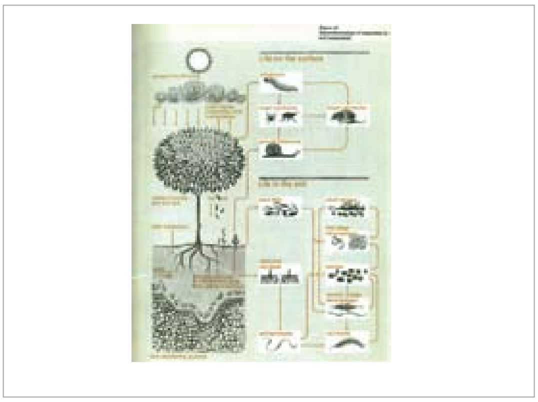
1948Pugh_S_NC

1956Spratt_E_CC

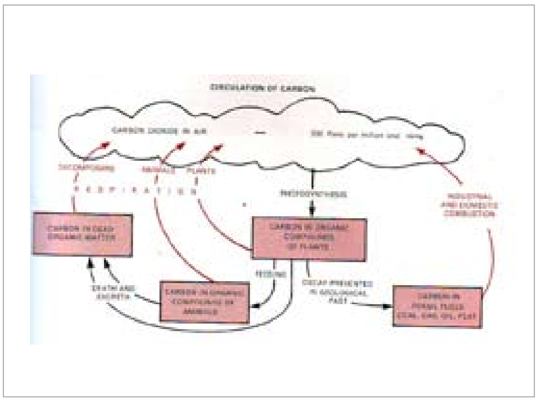
1962Spratt_E_CC



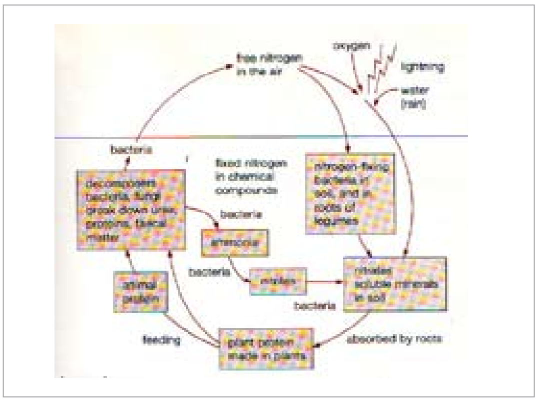
1964Green_M_NC



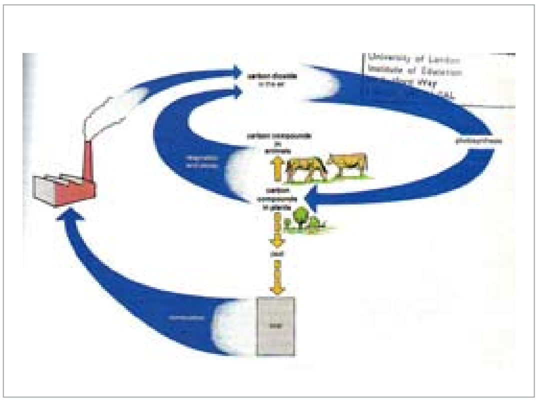
1966Nuffield_66CC



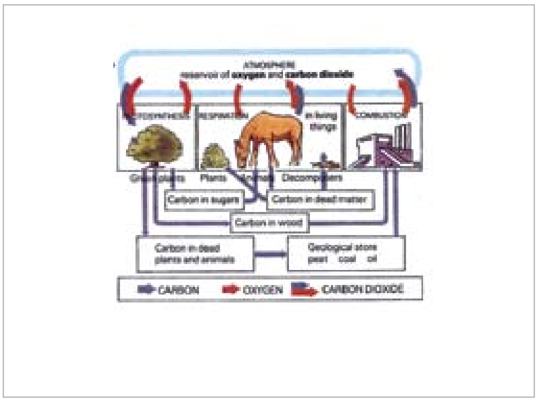
1985Brocklehurs_K_CC



1985Cadogan_A_CC

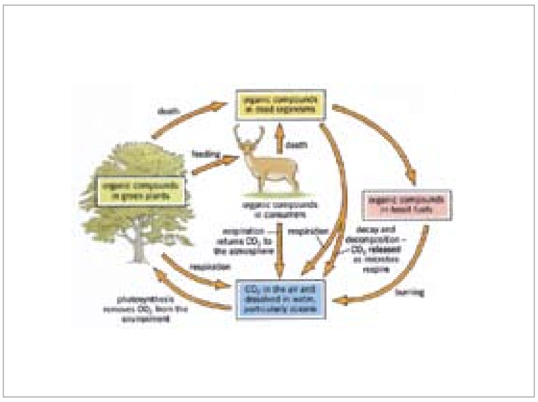


1986Roberts_M_CC

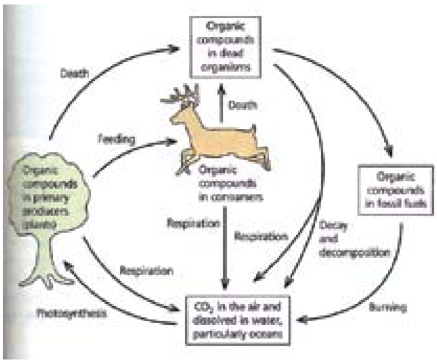


1992Cooper_S_CC

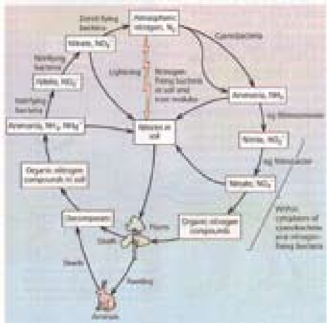
2000Churchman_J_NC



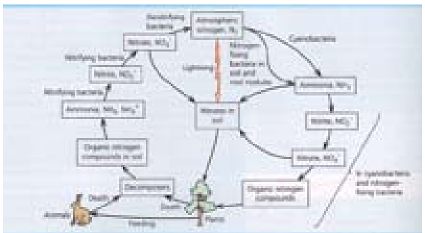
2000Fullick_A_CC



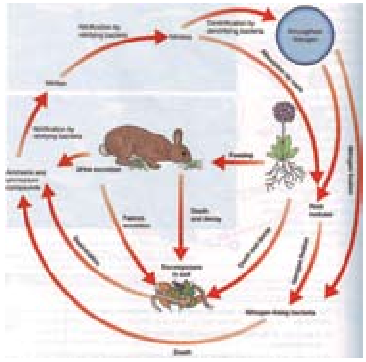
2000Fullick_A_CC2



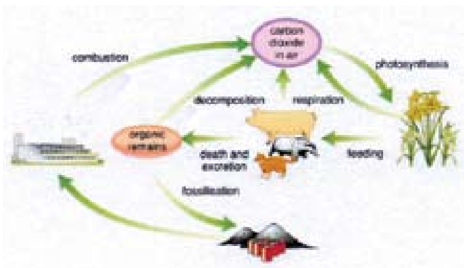
2000Fullick_A_NC



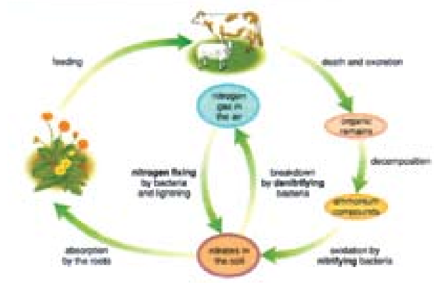
2000Fullick_A_NC1



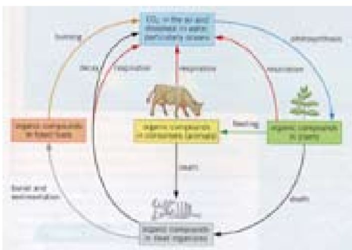
2000Lea_C_NC



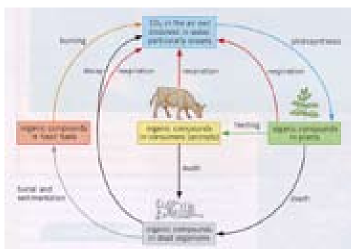
2001Dawson_B_CC



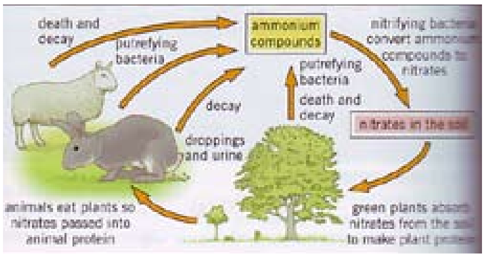
2001Dawson_B_NC



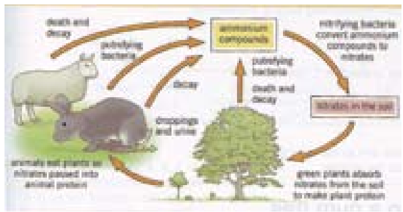
2001aFullick_A_CC



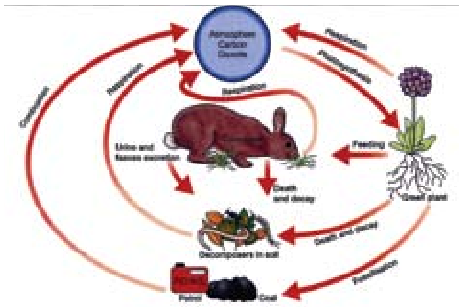
2001bFullick_A_CC



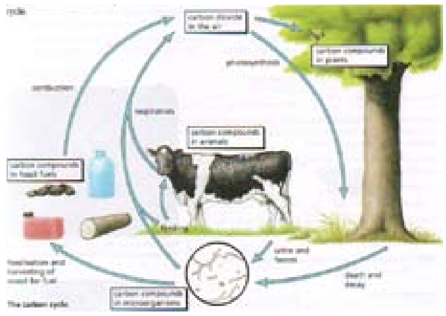
2001aFullick_A_NC



2001bFullick_A_NC

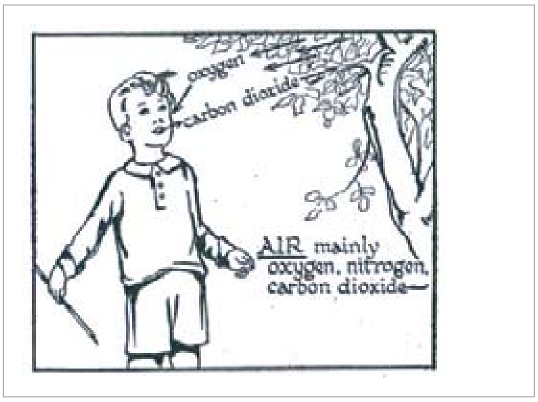


2001Lea_C_CC

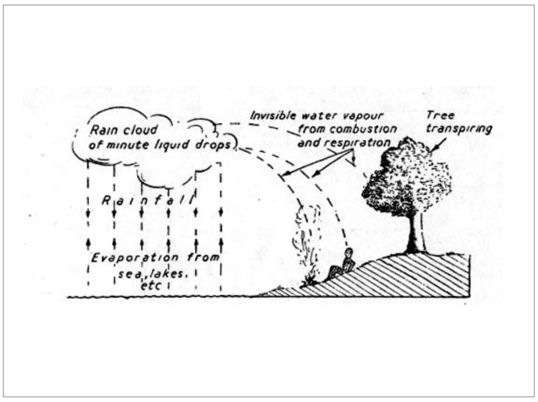


2008_Jones_M_CC

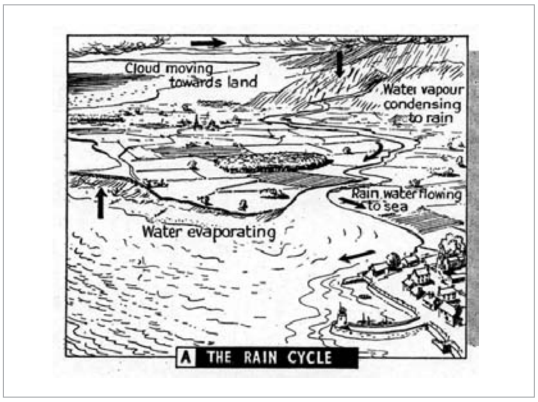
Appendix 3
UK Data set
Diagram group 5: text, arrow, and integral metric space.



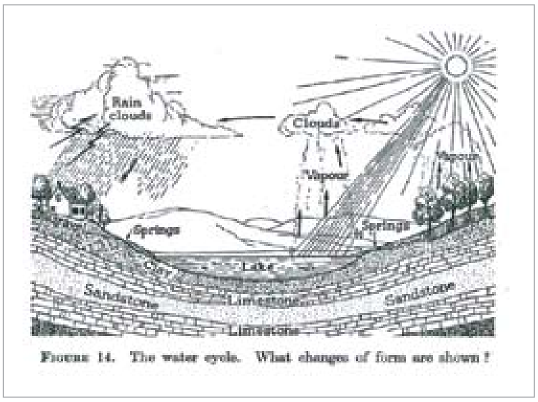
1935Little_W_CC



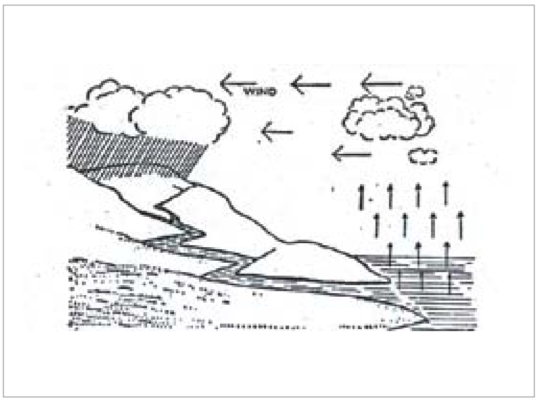
1950Swallow_S_WC



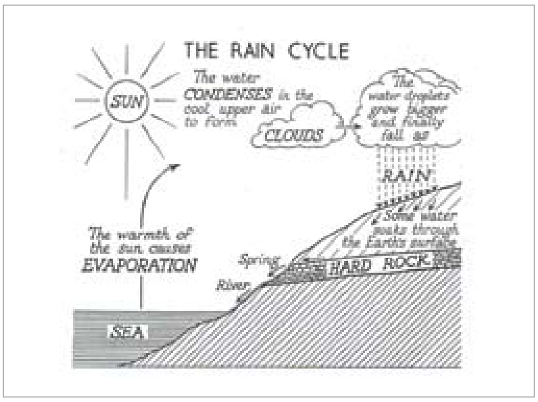
1952Webb_H_WC



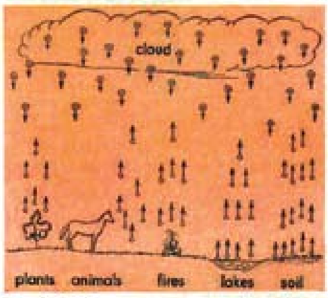
1954Clark_A_WC



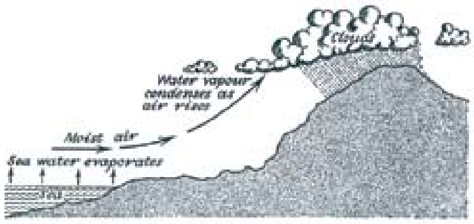
1954Daniel_F_WC2



1956Hanson_E_WC

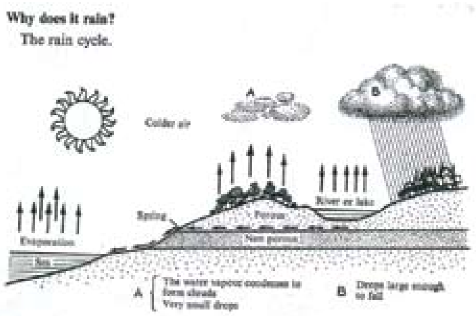


1958Obourn_E_WC

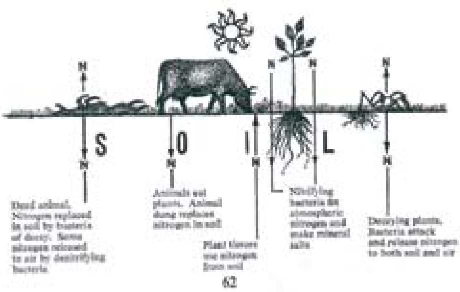


1960Western_W_WC

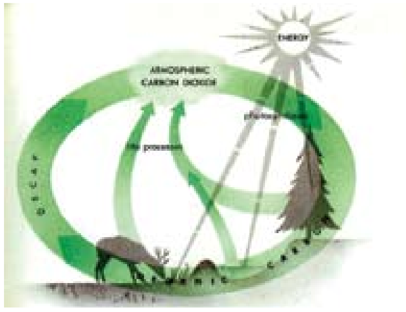
1961Barratt_D_WC



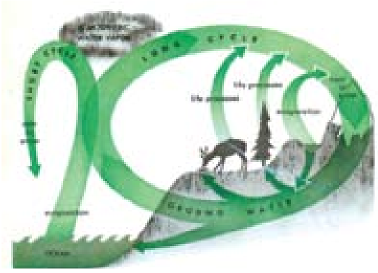
1962Chillingworth_D_WC



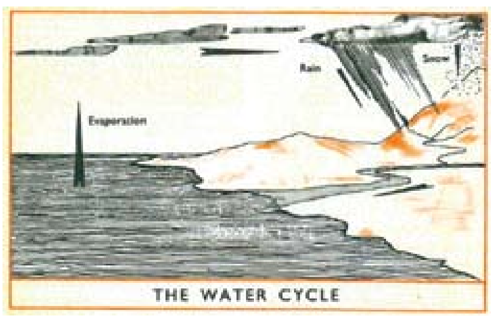
1962Knock_H_NC



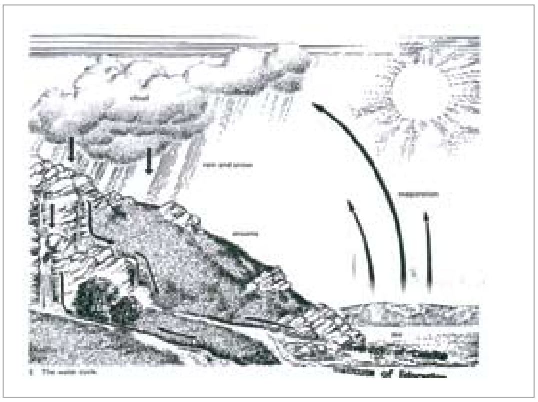
1963Kolb_H_CC



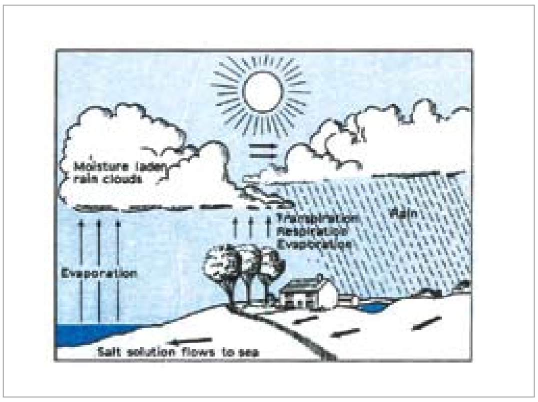
1963Kolb_H_WC



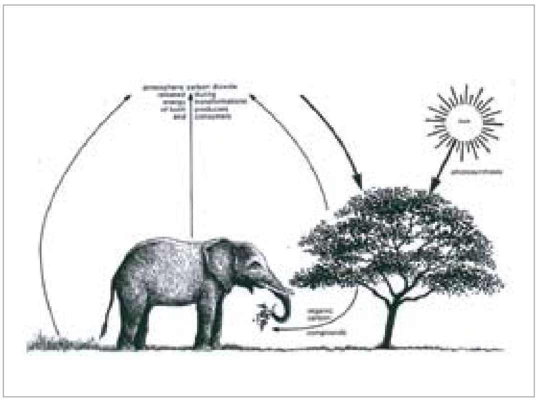
1968Barrell_F_WC



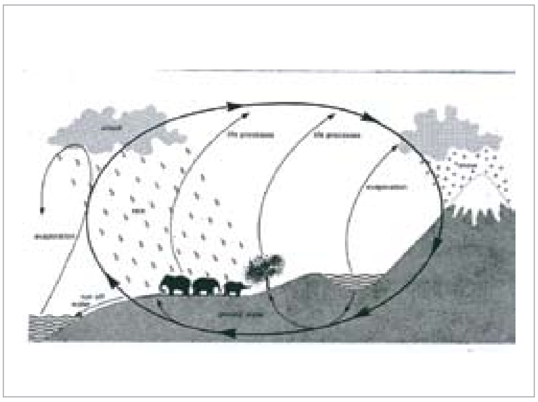
1968Chinery_M_WC



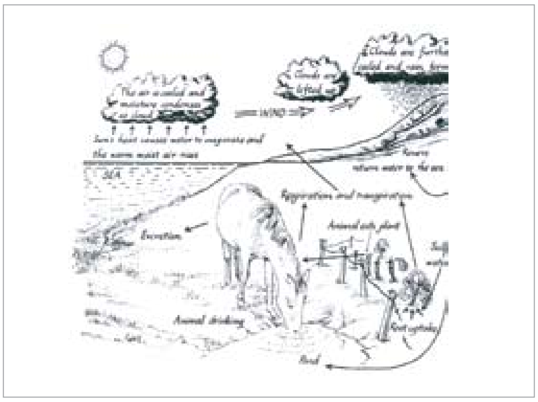
1968Simpson_O_WC



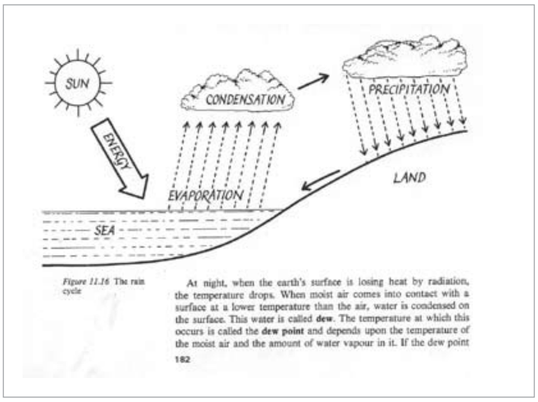
1972Ewer_D_CC1



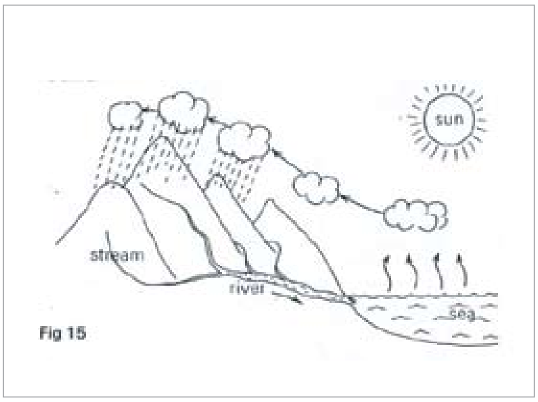
1972Ewer_D_WC



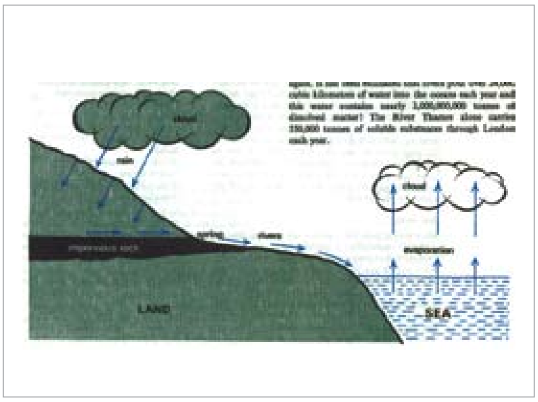
1972Ewington_E_WC



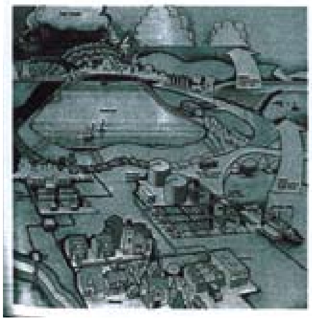
1972Savage_N_WC



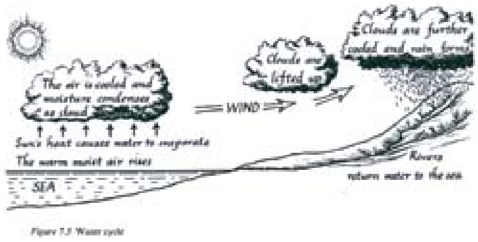
1976King_S_WC



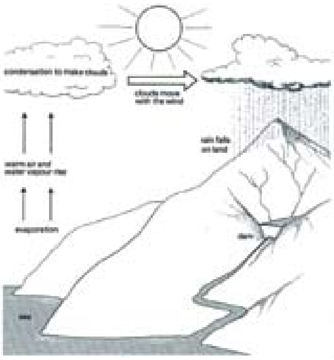
1977Cane_B_WC



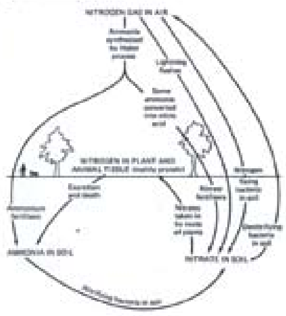
1977Latchem_W_WC



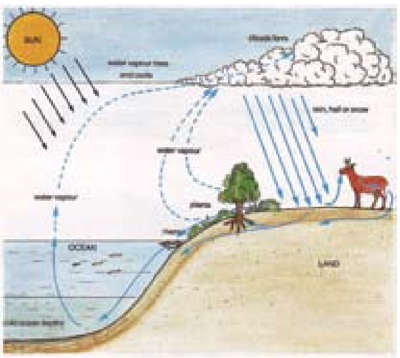
1978Campbell_J_WC



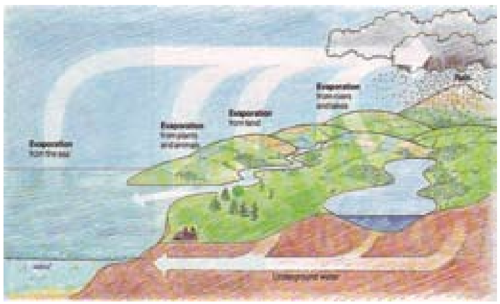
1979Dobson_K_WC



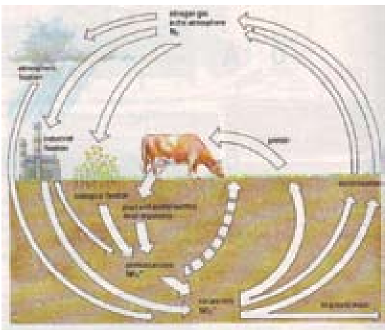
1982Ritchlow_C_NC



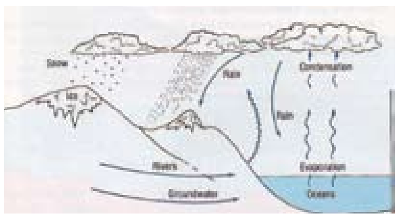
1986Cochrane_J_WC



1989Beckett_B_WC

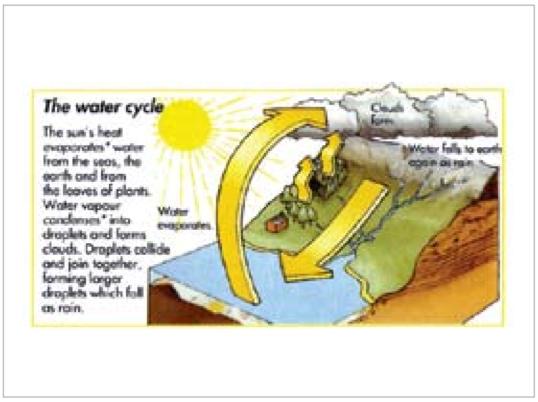


1989Nuffiled_NC

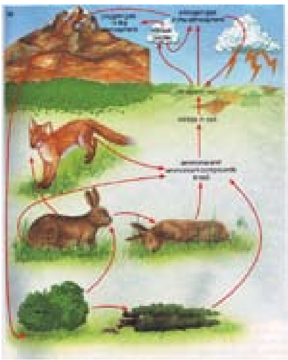


1992Bradberry_J_WC

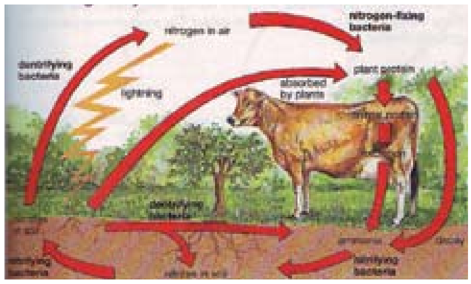
1992Cooper_S_WC



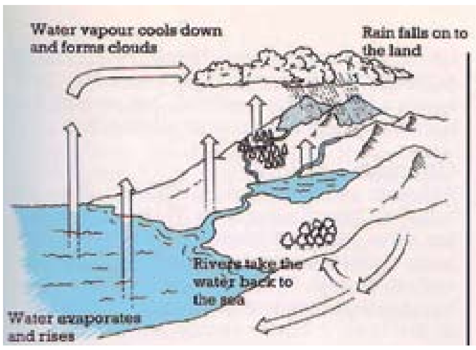
1992Treays_R_WC



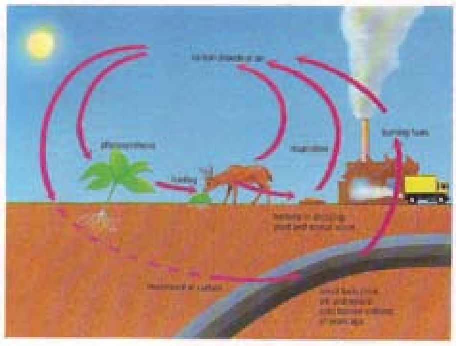
1993Hill_G_NC



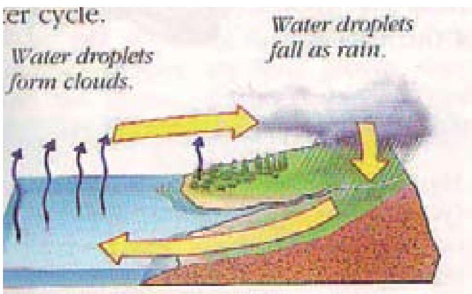
1994Sears_J_NC



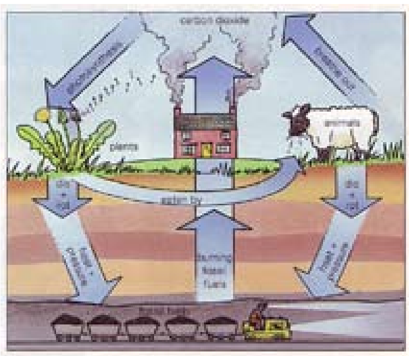
1994Seidenberg_S_WC



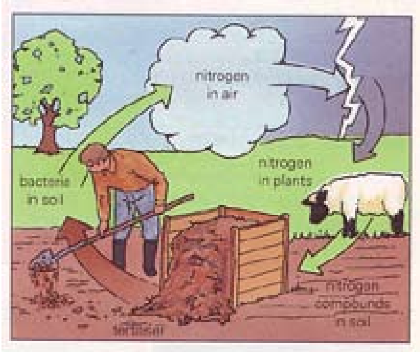
1994Taylor_C_CC



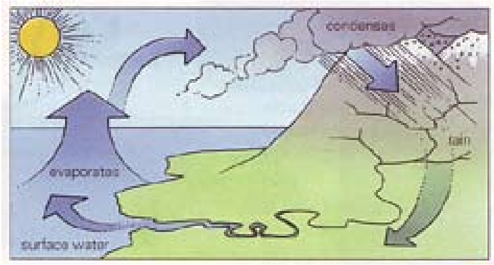
1994UWatts_L_WC



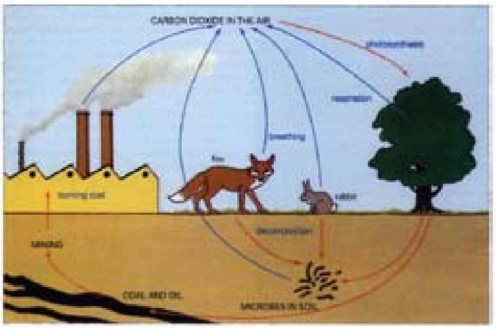
1996Bethell_A_CC



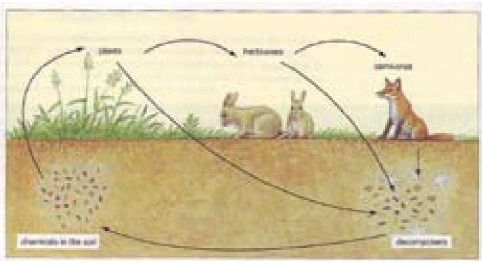
1996Bethell_A_NC



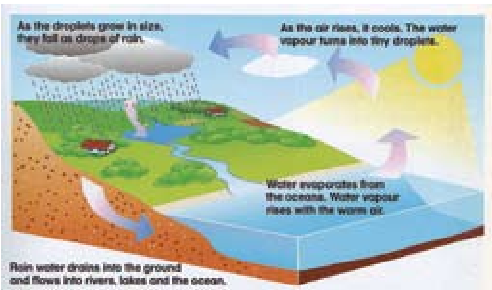
1996Bethell_A_WC



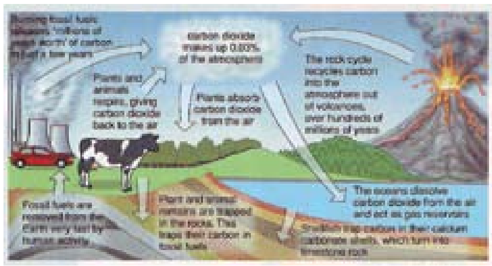
1996Stuart_A_CC



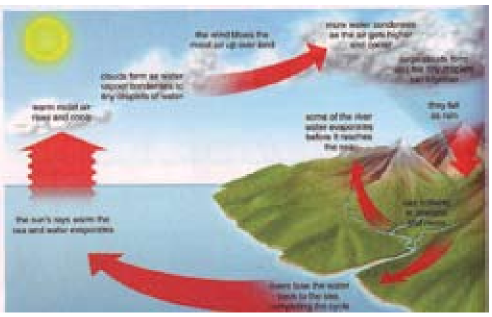
1996Stuart_A_CC



2000Bundey_N_WC

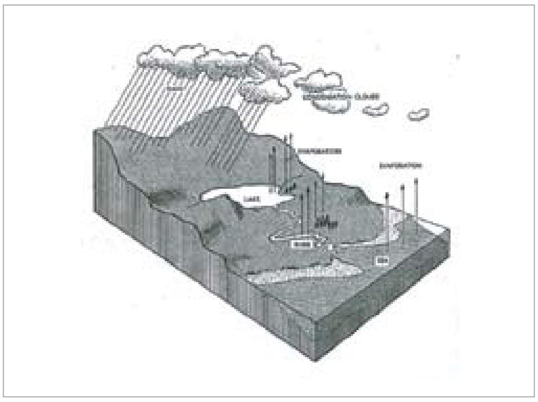


2001Hirst_K_CC

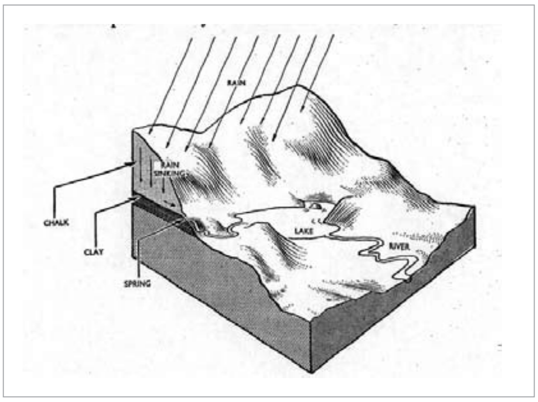


2001Hirst_K_WC

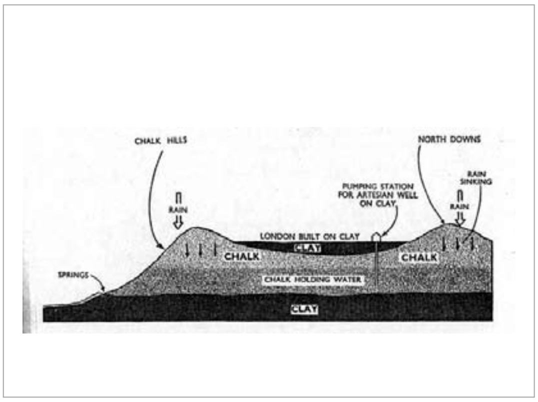
Appendix 3
UK Data set
Diagram group 6:
text, arrow, integral metric space, and container.



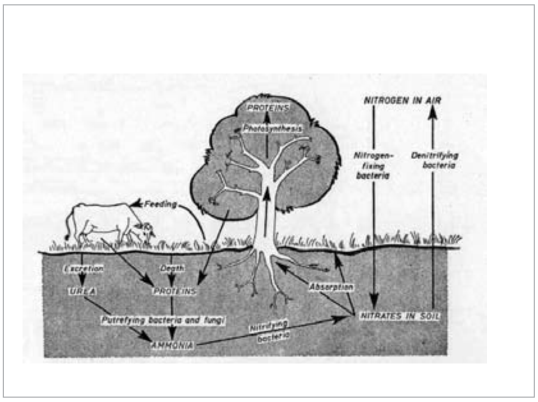
1955Pheasant_J_WC



1955Pheasant_J_WC



1955Pheasant_J_WC



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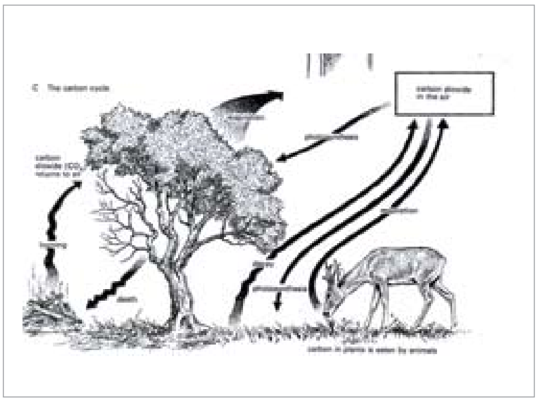

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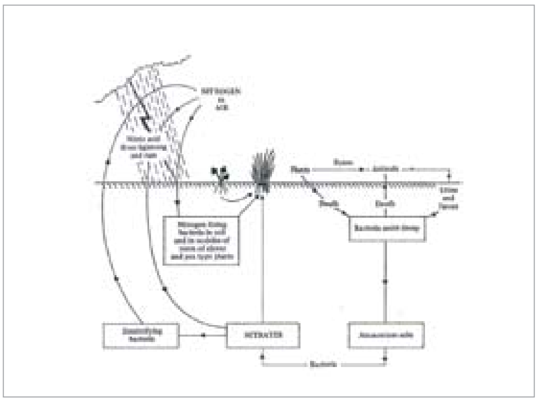

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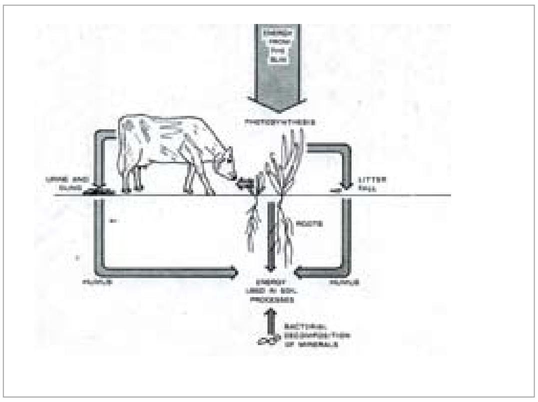

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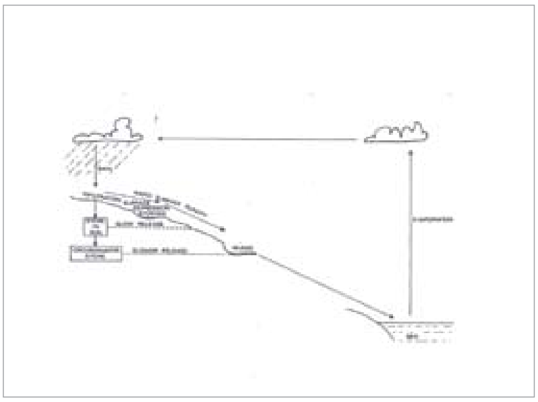

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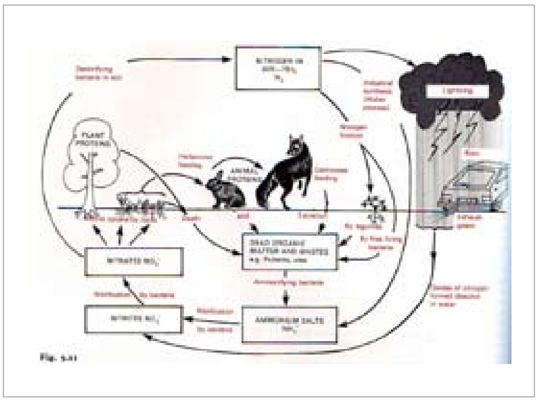

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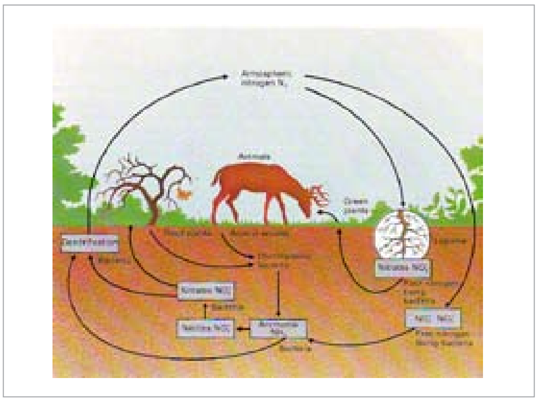

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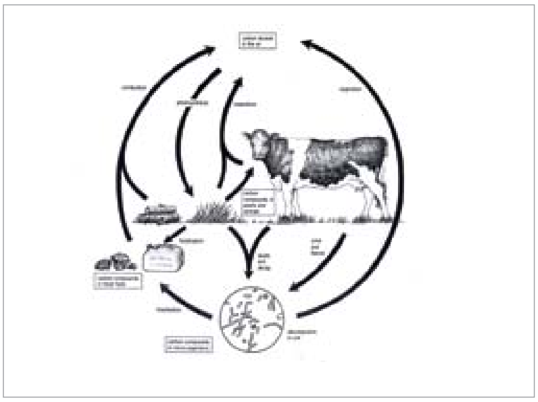

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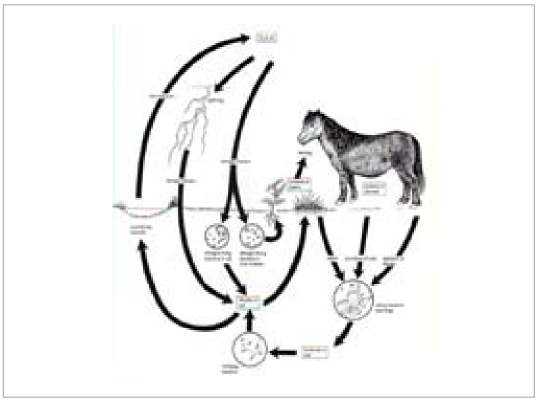

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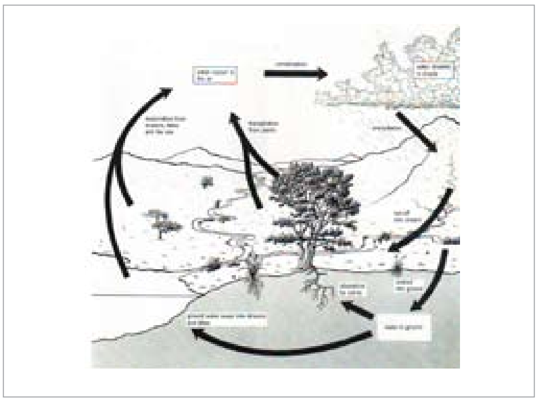

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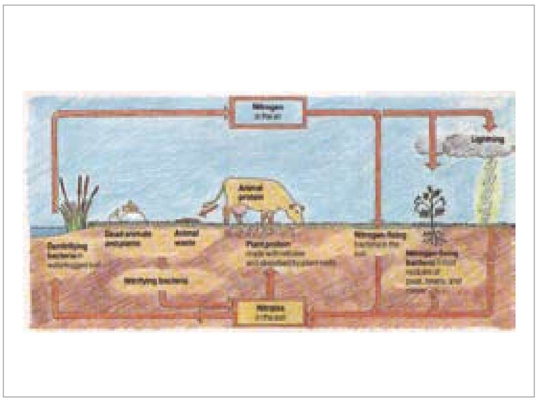

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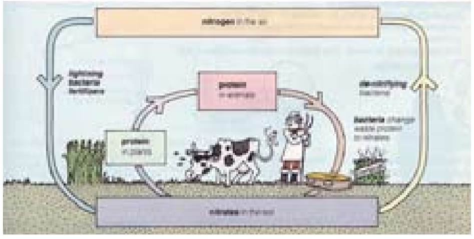

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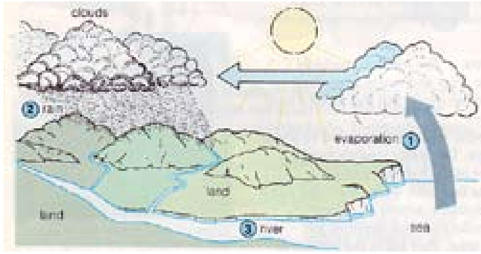

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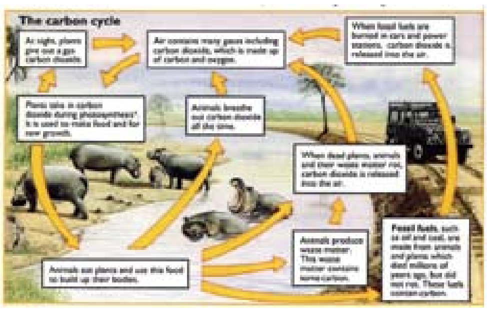

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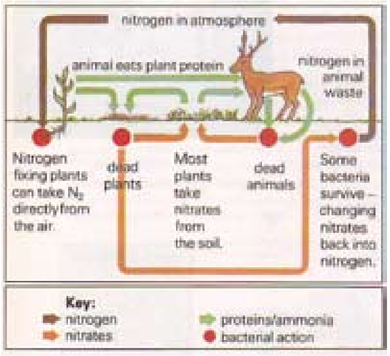

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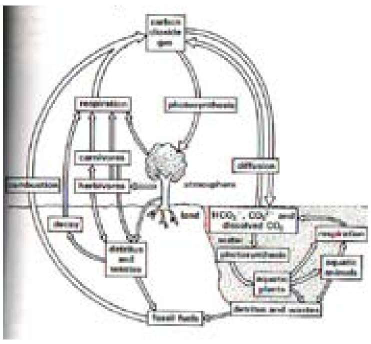

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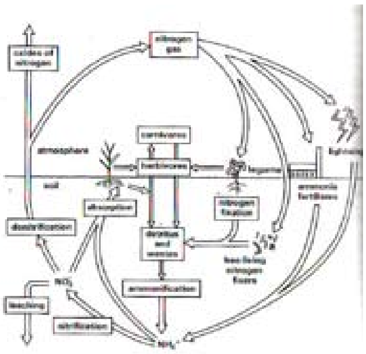

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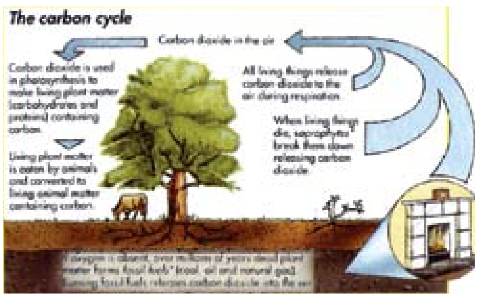

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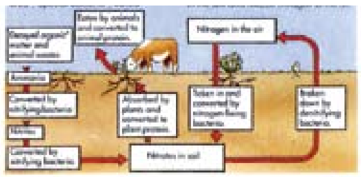

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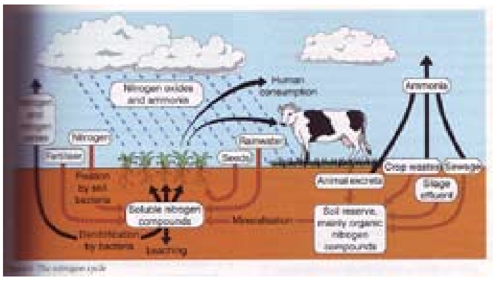

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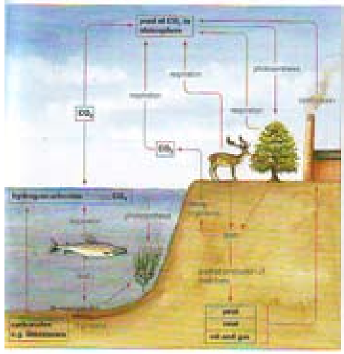

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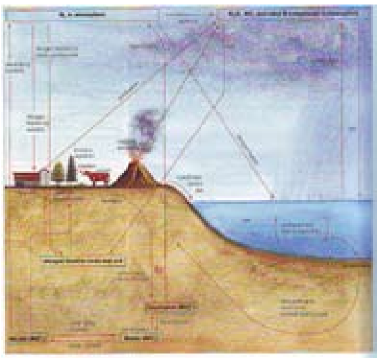

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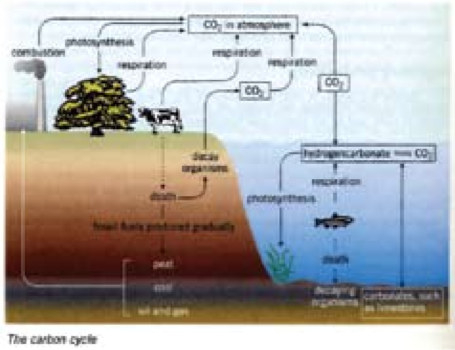

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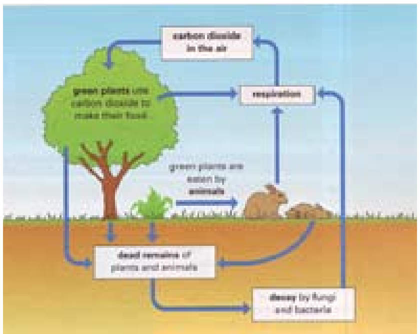

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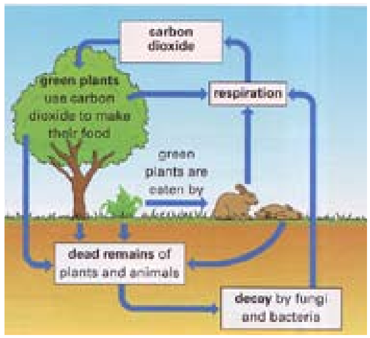

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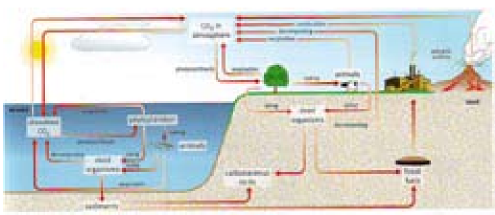

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Appendix 4
Definition of network diagram

A network diagram is defined in this thesis as a set of nodes and visually directed connectors, in which two or more nodes are linked in an open or closed loop [section 4.3.1.1]. This definition contributes to a refinement of the detail in Engelhardt's framework (2002). The definition was developed by including Engelhardt's four sub-categories of linking – 'linear chains', 'circular chains', 'tree diagrams', and 'networks' [section 4.3.1.1, figure 4.8] – as coding variables in the pilot analysis. This revealed ambiguity in Engelhardt's definition, which is discussed here to provide context for the definition applied in this research enquiry.

Engelhardt distinguishes between four types of linking centred on the concepts of *branching* and *closed loops* (2002: 40):

> 'A linear chain is a configuration of linking that involves no branching.
> A circular chain is a linear chain that forms a closed loop.
> A tree is a configuration of linking that involves branching from one root, with no closed loops.
> A network is a configuration of linking that involves one or more closed loops.'

Engelhardt defines a 'closed loop' based on the route options for moving from one node to another:

> 'A closed loop entails that there is more than one possible route for moving from one node to another.' (2002:40).

Engelhardt's 'circular chain' derives from a 'linear chain', *ie,* it is a 'circular chain' that excludes branching. It is also a 'closed loop' enabling at least two possible routes from one node to another. In a visually undirected circular chain [figure A4.1, next page], one may move from *a* to *d* either trough *a, b, c, d* or *a, f, e, d*.

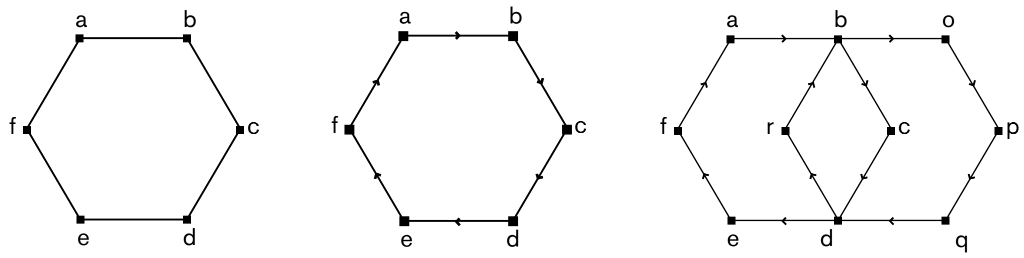


Figure A4.1: visually undirected circular chain
Figure A4.2: visually directed circular chain
Figure A4.3: visually directed network

However, in a visually directed circular chain [figure A4.2] the same task is limited to one route: *a, b, c, d.* Following Engelhardt's definition, figure A4.1 is a closed loop, whereas figure A4.2 is not. Similarly this problem occurs when applied to a visually directed network [figure A4.3]: moving from *o* to *e* can only be done through p, q and d in this example. With only one route from one node to another, this diagram disqualifies as a 'closed loop' in Engelhardt's definition. In figure A4.3 the branching enables two visually directed routes from *b* to *d*, one via *c*, and one via *p*, this qualifies as a 'closed loop', but not as a 'linear chain', given the branching. This contradiction in Englehardt's 'circular chain' definition in turn affects his network diagram definition. This finding enables refinement of the theory as part of this thesis. This refinement complements models preceding Engelhardt which offer only limited detail in their mention of linking sub-categories. Bertin (1983: 69) specifies 'networks' – here linking diagrams – as flow charts and trees based on inclusive relationships. Richards (1984) defines a linking category and mentions, *eg,* flowcharts and networks when discussing examples. Garland (1979) similarly distinguishes block diagrams and flowcharts.

In this thesis, a network diagram is defined as a set of nodes and visually directed connectors in which two or more nodes are linked in an open or closed loop. Open and closed loops here refers to the options for entering or exiting the network. A network diagrams' linking is here characterised, firstly, by the inclusion of branching or non-branching, and secondly, whether the linking is continuous or includes a beginning, an end-point, or both. A closed loop is in this thesis defined as an instance of continuous linking, *ie,* a network with no end or beginning point, *eg,* used to show global cycles or overall cycle concepts [figure A4.4]. In this definition a closed-looped cycle may include branching [figure A4.5], thereby comprising several sub-cycles *eg*, between 'carbon dioxide in the air' [a] and 'manufactured food in plants' [b] through both 'photosynthesis' [c], and 'respiration' [d]; forming a closed-looped network with branching.

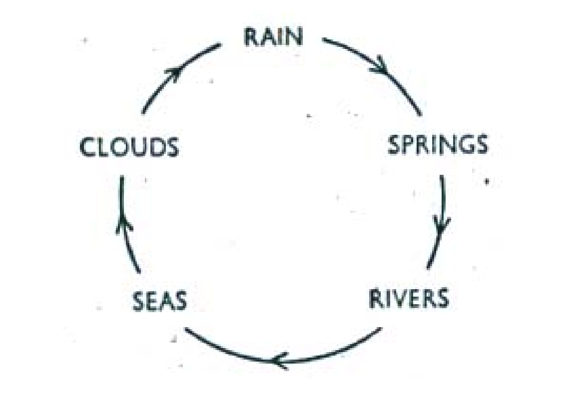


Figure A4.4: Diagram no 029

Graphic syntax aspect highlighted
Network diagram type: Continuous and non-branching

The water cycle
From: Daniel (1954: 102)

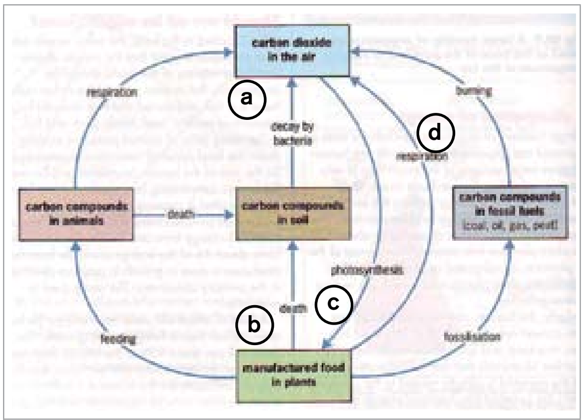


Figure A4.5: Diagram no 095

Graphic syntax aspect highlighted
Network diagram type: Continuous and branching

The carbon cycle
From: McDuell (1994: 110)

In figure A4.6 the pictorial node of a forest fire [a] has an arrow exiting but none entering. The content proper message could here be interpreted as a forest fire being the starting point for the carbon cycle. Figure A4.7 on the other hand terminates the cycle in 'in rocks carbonates' [a]. Figure A4.8 combines these points, positioning 'fires' [a] as a beginning point and 'corals shells etc' [b] as the end of the cycle.

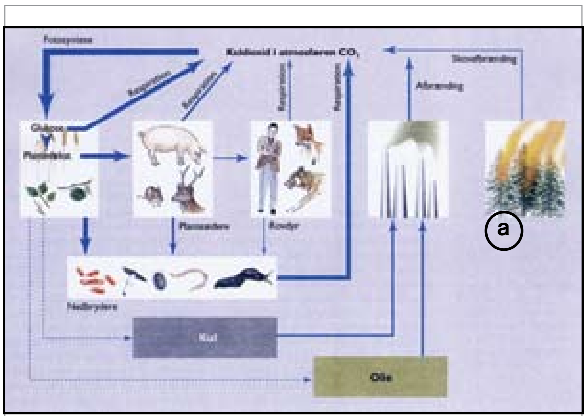


Figure A4.6: Diagram no 250

Graphic syntax aspect highlighted
Network diagram type: Branching with beginning point

The carbon cycle
From: Paludan-Müller (2002: 17)

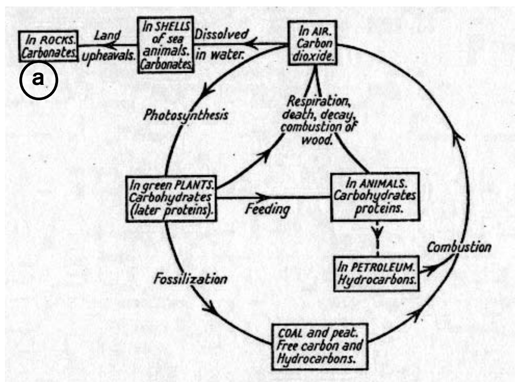


Figure A4.7: Diagram no 063

Graphic syntax aspect highlighted
Network diagram type: Branching with end point

The carbon cycle
From: Whitehouse and Pritchard (1948: 197)

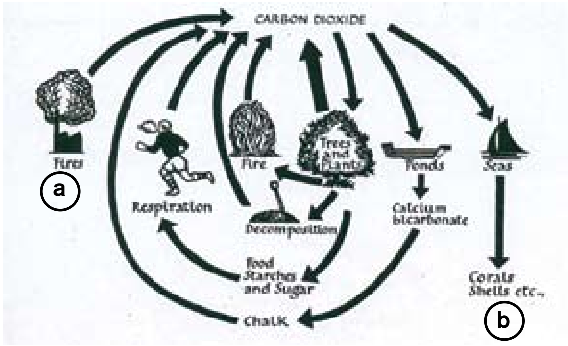
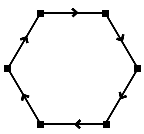
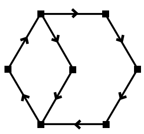
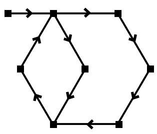
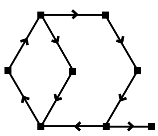


Figure A4.8: Diagram no 109

Graphic syntax aspect highlighted
Network diagram type: Branching with beginning and end point

The carbon cycle
From: Reed (1958: 106)

This demonstrates how the choice of network diagram structure affects the *graphic syntax's* message about the *content proper*. Figure A4.6 and figure A4.8 could be interpreted as if the ecological cycle 'starts' through fires. Ending the cycle in corals or rocks, on the other hand, indicates unlimited storage. Both messages may be interpreted as one defined journey or flow through the cycle, thereby contrasting the essential message of continuous circulation. Table A4.1 summarises the refined definitions of network diagrams.

Visual strategy	**Object-to-object relation**	**Content proper message**
Networks - closed looped		
	Continuous and non-branching	Continuous cycle with no sub-cycles
	Continuous and branching	Continuous cycle with sub-cycles
Networks - open looped		
	Branching with beginning point	Cycle with indicated starting point, *ie,* input
	Branching with end point	Cycle with indicated end point, *ie,* output

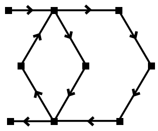
	Branching with beginning and end point	Cycle with indicated start and end point, *ie*, input and output

Table A4.1: Definition of network diagrams.

Appendix 5
Semantic definition of general information types in ecological cycle network diagrams

This appendix documents the semantic definition of general information types [section 4.3.2.3], developed by extracting terminology from the collected ecological cycle network diagrams during the pilot visual content analysis. The information types are defined based on verbal descriptions in existing diagrams. Annotations which include multiple information type are excluded here.

Organism
Any living organism

- Animal
- Animals
- Aquatic carnivores
- Aquatic herbivores
- Bacillos mycoides
- Bacteria
- Bacteria fungi
- Carnivore
- Carnivorous animals
- Clover
- Consumer
- Decomposers
- Decomposition bacteria
- Denitrifying bacteria
- Detritivores decomposers
- Fox
- Fungi
- Grass
- Green plant
- Herbivore
- Herbivorous animals
- Human,
- Humans
- Legume
- Legumes
- Marine algae
- Microbe,
- Microbes
- Most plants
- N-fixing bacteria
- N-freeing bacteria
- Nitrifying bacteria
- Nitrogen fixing bacteria
- Plants
- Rabbit
- Roots
- Saprophytes
- Soil organisms
- Some bacteria
- Some plants

Matter
Matter described by scientific terminology

- Amino acids
- Ammonia
- Ammonia (NH_3)
- Ammonium carbonate
- Ammonium carbonate ($-NH_4)_2CO_2$
- Ammonium compounds
- Ammonium ions (NH+4)
- Ammonium ions NH_4+
- Ammonium NH_4+
- Ammonium salts
- Amino-compounds
- Animal carbohydrate
- Animal carbohydrates
- Animal protein
- Animal proteins
- Animal protoplasm
- Atmospheric {CO_2 H_2O}
- Atmospheric carbon dioxide
- Atmospheric nitrogen
- Atmospheric nitrogen (N_2)
- C
- Calcium bicarbonate
- Calcium carbonate
- Carbohydrates
- Carbon compounds
- Carbon dioxide
- Carbon hydrates
- Carbonic acid
- CO_2
- Dissolved carbon dioxide
- Free nitrogen
- Glucose
- H_2O
- HCO_3-
- Living protoplasm
- N
- N_2
- N_2 (gas)
- N_2 nitrogen
- N_3
- $NH_3 + N_2$
- NH_4+ Ammonium
- Nitrates
- Nitrates (NO_3-)
- Nitrates etc.
- Nitrates sulphates etc
- Nitrifying
- Nitrite
- Nitrites
- Nitrites ($NO-_2$)
- Nitrogen
- Nitrogenous excretion
- Nitrous oxide
- O
- O2
- Oxygen
- Plant carbohydrates
- Plant protein
- Protein
- Proteins
- Protoplasm of animals
- Soil nitrates
- Urea

Material
Larger human made or natural masses of matter and more inclusive terminology

- Animal excreta
- Animal excretion
- Animal food
- Animal manure
- Animal tissues
- Animal waste
- Apples and pears
- Beans
- Candles
- Cars
- Clouds
- Coal
- Compost
- Dead animal material
- Dead bodies
- Dead body
- Dead organic material
- Dead parts
- Dead plant material
- Dead plants
- Detritus
- Droppings
- Factories
- Fallen leaves
- Fertiliser
- Fire
- Food
- Foodstuffs
- Fossilised animals
- Fossilised plants
- Fossils fuels (oil, coal, gas, peat and shale)
- Fuels
- Gas jets
- Gasworks
- Humus
- Industry
- Limestone
- Logs
- Mined coal
- Mollusc skeletons etc
- Nuts
- Organic remains
- Paraffin
- Peas
- Peat
- Petrol
- Petroleum
- Plant tissues
- Rain
- Rainwater
- Salts
- Seeds
- Sewage
- Shelled animals
- Springs
- Tissue
- Waste products
- Water
- Yeast

Pool
Large and continuous storages of matter

- Air
- Lake
- Lakes
- Land
- Land area
- Natural deposits
- River
- Rivers
- Sea
- Seas
- Soil
- Springs

Process
Processes described with nouns or verbs

- Absorb
- Absorbed
- Animal respiration
- Atmospheric fixation
- Biological fixation
- Boiling
- Buried
- Burning
- Carbonisation
- Chemical methods
- Chemosynthesis
- Coal formation
- Combustion
- Death
- Decay
- Decomposed
- Decomposes
- Decomposition
- Denitrifying
- Die
- Dissolving
- Eat
- Eaten
- Eaten
- Excretion
- Feeding
- Fossilisation
- Further decomposition
- Haber process
- Human consumption
- Industrial combustion
- Industrial fixation
- Lightning
- Mining
- Organic decomposition
- Oxidation
- Photosynthesis
- Photosynthesis
- Plant respiration
- Reproduction
- Respiration
- Rock formation
- Rot
- Sedimentation
- Thunderstorms
- Uptake
- Urine excretion

Energy and force
Explicit mention of energy or force

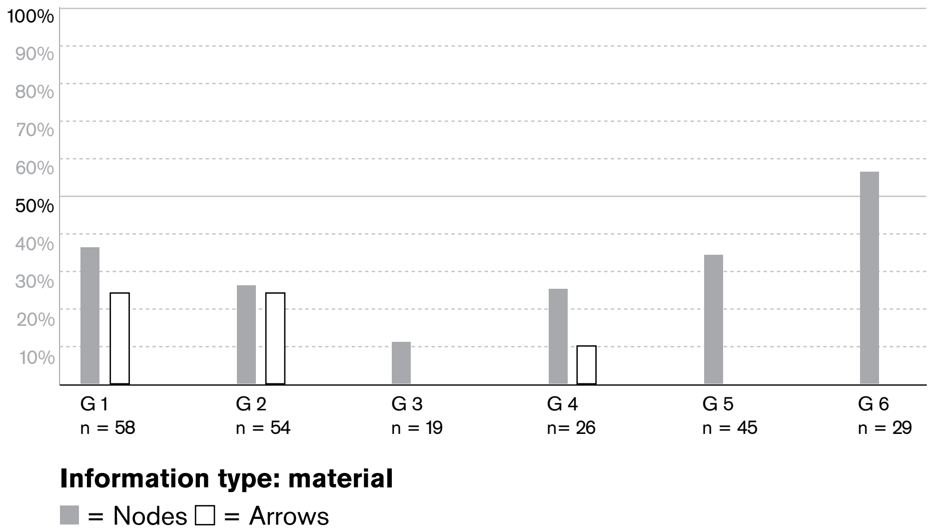
Chemical energy
Energy
Heat
Pressure
Sun
Sunlight
Wind

Appendix 6
Frequencies of coding values

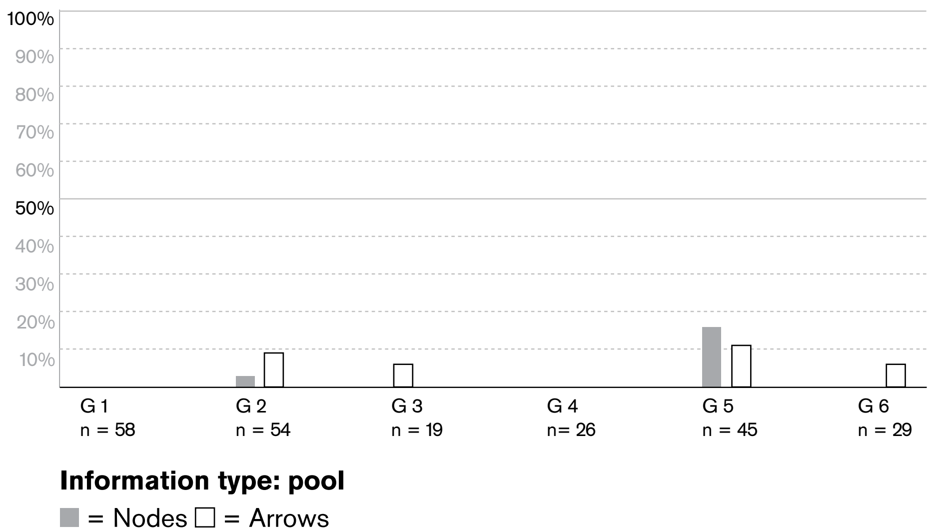
This appendix presents frequencies of 'neutral' coding values. These are part of the data trail ensuring a transparent visual content analysis [chapter 5].

A6.1 Coding variable 1: node and connector syntactic roles

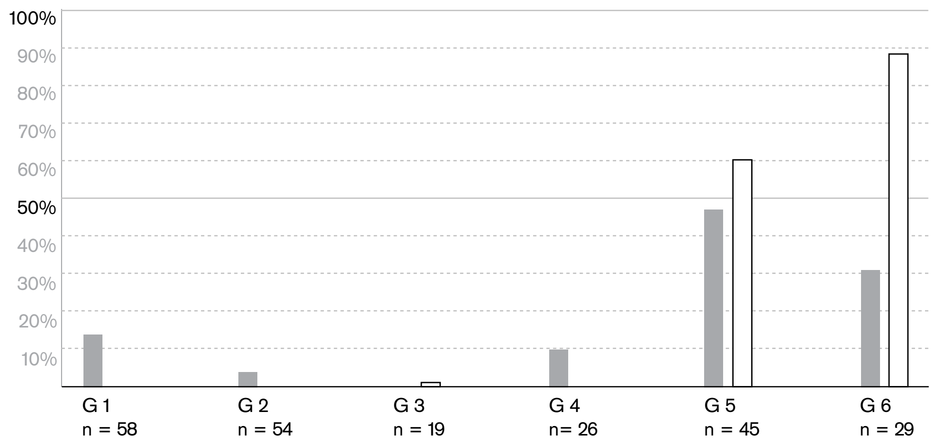
Frequency of coding values for single information types material, pool, and energy and force [section 5.2.3].



Bar chart A6.1: Frequency of coding value for material information type



Bar chart A6.2: Frequency of coding value for pool information type

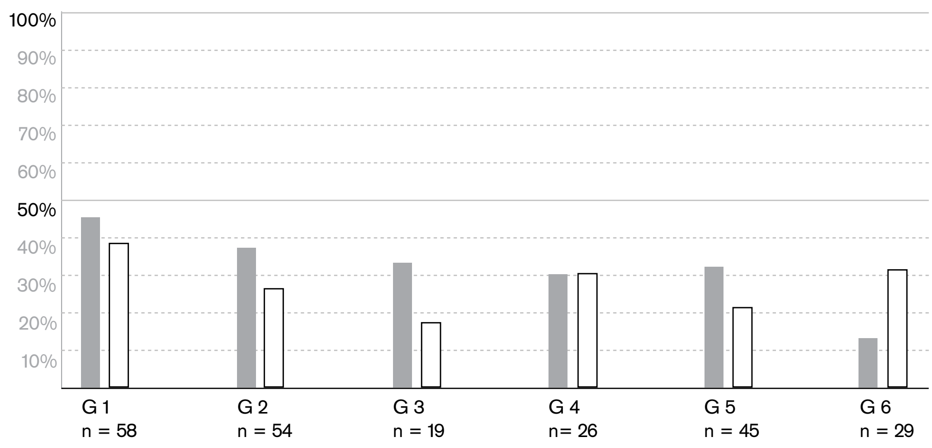


Information type: energy and force

■ = Nodes □ = Arrows

Bar chart A6.3: Frequency of coding value for energy and force information type

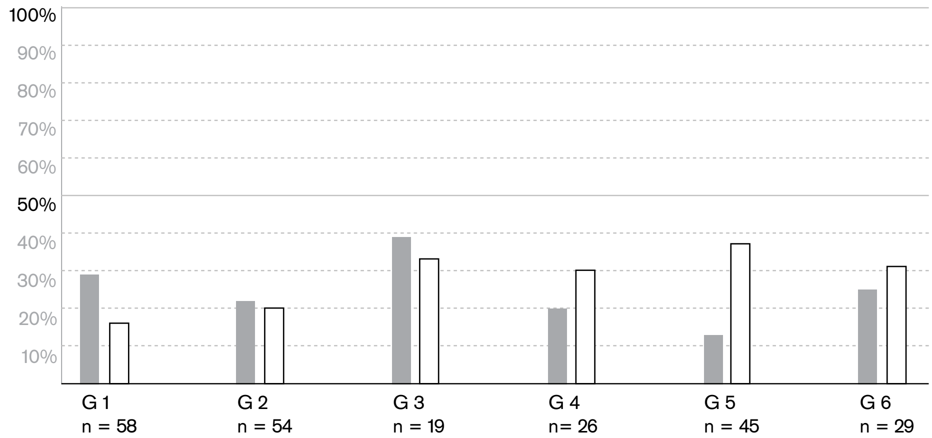
A6.2 Coding variable 1: frequency of coding values within same syntactic role [section 5.2.3.4].



2 coding values within same syntactic role

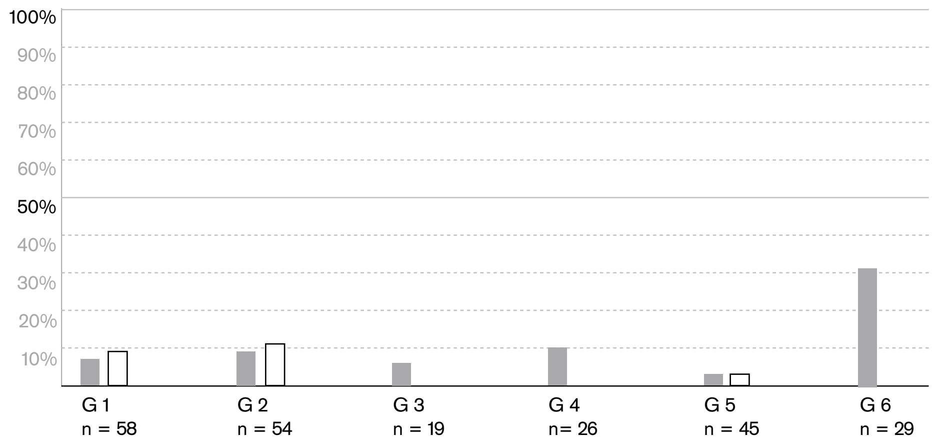
■ = Nodes □ = Arrows

Bar chart A6.4: Frequency of diagrams with 2 coding values within same syntactic role.



3 coding values within same syntactic role
■ = Nodes □ = Arrows

Bar chart A6.5: Frequency of diagrams with 3 coding values within same syntactic role.

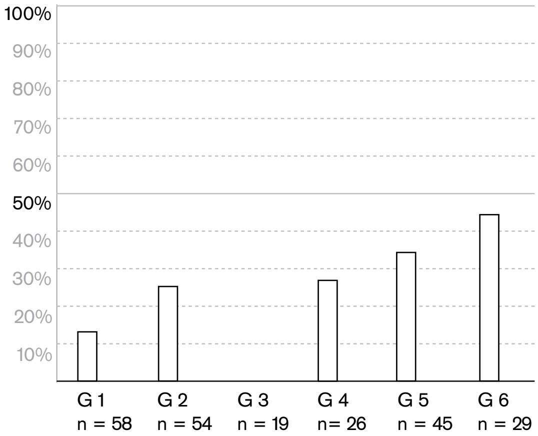


4 coding values within same syntactic role
■ = Nodes □ = Arrows

Bar chart A6.6: Frequency of diagrams with 4 coding values within same syntactic role.

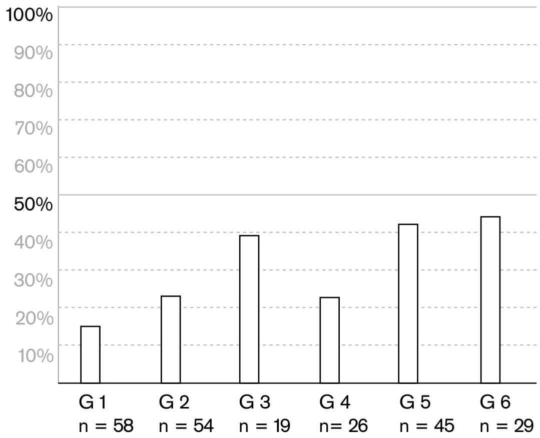
A6.3 Coding variable 3: frequencies of arrow coding values

[section 5.4.2.1]



Two arrow coding values

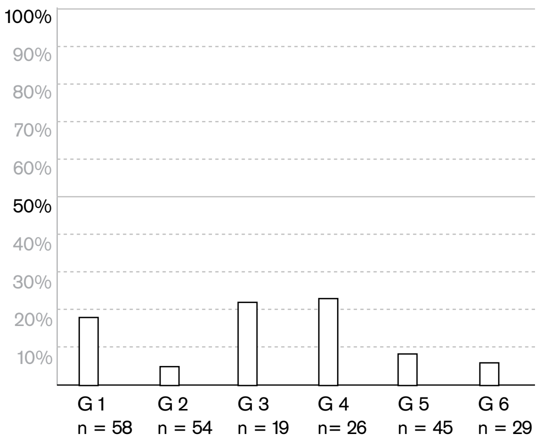
□ = Arrows



Three arrow coding values

□ = Arrows

Bar chart A6.7: Frequency of diagrams with 2 arrow coding values.
Bar chart A6.8: Frequency of diagrams with 3 arrow coding values.



Four arrow coding values

□ = Arrows

Bar chart A6.9: Frequency of diagrams with 4 arrow coding values.

Appendix 7
Verbal and graphic syntax interactions

This appendix presents additional findings from the visual content analysis, revealing some key issues for graphic tactics within verbal syntax, when seen as a graphic syntax aspect. These findings reveal four general ineffective graphic tactics [section 5.7.1]:

- Inconsistent linear linked verbal syntax
- Inconsistent noun and verb phrases
- Inconsistent passive and active voice
- Inconsistent prepositions

These theoretical contributions may serve as corner stones in future detailed mapping of this interesting junction between graphic and verbal syntax.

A7.1 Verbal and graphic syntax interactions

Richards (1984), in his model of graphic syntactic relations, applies grammatical noun- and verb-spaces as an analogy [section 4.4.1]. The non-linear nature of graphic syntax prevents any closer comparison to the linearly controlled verbal syntax sentence structure. Instead graphic syntax discussions often centre around the nature of different routes within linking diagrams, *ie,* applying a cartographic analogy. In contrast to a verbal sentence, a set of linked graphic objects offers several routes for reading, with any of the graphic objects as the starting point; for example, the simultaneous readings of 'the nodes are connected by the arrow' and 'the arrow connects the nodes'. However, parallel with this non-linear graphic syntax – in network diagrams – exists a potential verbal linking created by text objects included in the nodes and arrow labels. If the verbal syntax in the nodes and arrow labels is kept 'simple', then the verbal linking may be read using the two routes through the graphic syntax linking. Figure A7.1 [next page] demonstrates a 'simple' verbal syntax by including mainly nouns – with some adjectives or coordinators – enabling two reading options regardless of arrow direction:

'Nitrates' [a] are connected to 'nitrites' [b] by 'bacterial action' [c],

or

'Bacterial action' [c] connects 'nitrites' [a] and 'nitrates' b].

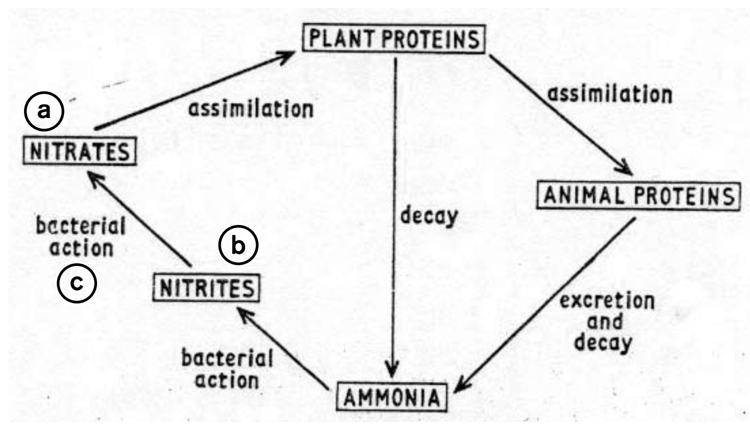


Figure A7.1: Diagram no 077
Graphic syntax aspect highlighted Verbal and graphic syntax interrelations: Simple verbal syntax through nouns in arrows and nodes.
The nitrogen cycle From: Vernon (1967: 265)

Several interesting examples in the data set contrast the above 'simple' verbal syntax example; the verbal syntax instead linking within graphic objects. When more verbal elements are added to nodes or arrow labels, the relationship between verbal and graphic linking may become misaligned and potential ineffective, as demonstrated by the following four ineffective graphic tactics.

A7.2 Inconsistent linear linked verbal syntax

Ecological cycle network diagrams may include full sentences in text objects, creating a linear – or almost linear – prose when reading through the nodes and arrow labels. Such text objects are common within integral metric spaces – diagram groups 5 and 6 – representing a supplementary image-text relation (Schriver, 1997: 419) by 'unpacking' the illustration. Such verbal linking may emphasise or strongly direct a network diagram's visual routing. If applied inconsistently, however, the verbal linking becomes misaligned with the visual routes. This may confuse the content proper message about beginning and exit points in the cycle, as demonstrated by figure A7.2 [next page].

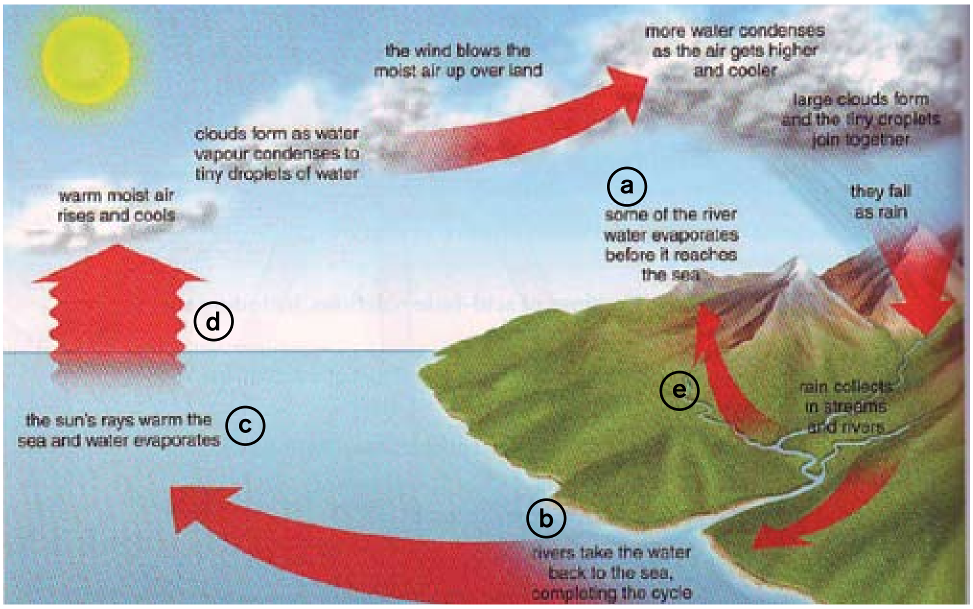


Figure A7.2 / Diagram no 143

Graphic syntax aspect highlighted
Verbal and graphic syntax interrelations:
Inconsistent verbal syntax, linear linked within graphic objects.

The water cycle
Hirst *et al* (2001: 38)

In figure A7.2 the nodes are linked through linear verbal syntax, running parallel with the visual linking. The linearity is broken, however, by the node 'some of the river water…' [a], which has no exit point – thereby indicating a visual end-point to the linking. This visual end-point is misaligned with the linear verbal linking, which includes a verbal starting- and end-point to the linking. The node 'rivers take the water back to the sea, completing the cycle' [b] indicates a finishing point, thus the node 'the sun's rays warm the sea and water evaporates' [c] may be interpreted as a starting point. The graphic syntax is thereby a network diagram with an end-point, whereas the verbal syntax includes a start and finishing point. To add to this confusion, the verbal and visual start points appear in different places. Apart from complicating the reader's interpretation, the addition of starting and end points here represents an inherent conflict with the continuous circulative nature of water cycles.

In the space between a simple noun verbal syntax and linear linked sentences exist shorter noun and verb phrases. These may also be inconsistent.

A7.3 Inconsistent noun and verb phrases

Shorter noun and verb phrases represent simplified verbal linking within nodes and connectors. A general ineffective graphic tactic here arises, firstly, when the verbal linking is inconsistent, resulting in 'breaking' the linear verbal link within graphic text objects; secondly, when both noun and verb phrase clauses are applied. Both these general ineffective graphic tactics relate to the absence of positive redundancy as demonstrated in the following example; using five node-arrow-node connections [1-5] from figure A7.3.

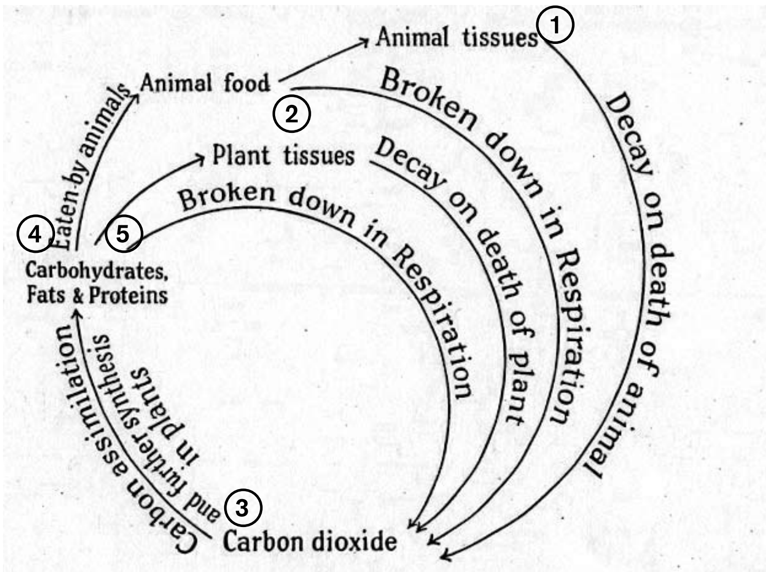


Figure A7.3: Diagram no 007

Graphic syntax aspect highlighted
Verbal and graphic syntax interrelations:
Four node-connector-node sequences representing noun and verb phrases.

The carbon cycle
Phillips and Cox (1936: 175)

Graphic syntax		Node/noun space	Connector/verb space ⟶	Node
Verbal syntax	1	Animal tissues	Decay on death of animal	Carbon dioxide
	2	Animal food	Broken down in respiration	Carbon dioxide
	3	Carbon dioxide	Carbon assimilation and further synthesis in plants	Carbohydrates, Fats & Protein
	4	Carbohydrates, Fats & Protein	Eaten by animals	Animal food
	5	Carbohydrates, Fats & Protein	-	Plant tissues

Table A7.1: Verbal syntax extracted from nodes and arrow labels in figure A7.3.

It is appropriate here to revisit basic English grammar (Collins and Hollo 2000) and the basic components of a clause. This analysis focuses on subjects, verbs and objects, thereby excluding discussions of elements such as complements and adverbs. A clause is a simple sentence composed from clause elements. Clause elements are single words, or phrases, which are groups of words. The focus in this analysis is on grammatical subjects, verbs, and objects, and the role played by phrases within a clause. Here demonstrated using the clause 'green plants release carbon dioxide':

Subject	**Verb**	**Object**
Identifies the theme, or 'actor' of a sentence.	Communicates an action or state of being	Identifies a person or object affected by the verb
'Green plants'	'release'	'carbon dioxide'

Table A7.2: Roles of grammatical subjects, verbs, and objects within a clause.

A noun phrase is the main element of a clause, consisting of one or more nouns, and can appear as subject or object. A verb phrase, meanwhile, is the verb element in a clause and can consist of one or more verbs, *eg*, 'is released'. These basic grammatical roles are further expanded throughout the two following sections. For now, the analysis identifies noun and verb phrases within the clauses of the five node/connector sequences from figure A7.3; the prepositions are discussed in section A7.5.

Node-connector-node combination 1 presents a clause with both noun and verb phrase elements, applied as subject, verb, and object within the two first graphic text objects:

1	Noun phrase/subject	Verb phrase with object	Noun phrase/subject
	'Animal tissues'	'Decay on death of animal'	'Carbon dioxide'

Table A7.3: Node-connector-node combination 1 from figure A7.3.

The verbal continuity is broken by continuing with the noun phrase 'carbon dioxide', omitting, *eg,* 'releasing' carbon dioxide or a similar verb. Thereby the invitation to read a linear sentence ends abruptly when reaching the third connected graphic text object.

Node-connector-node combination 2 can similarly be read as a verb phrase clause, although here a component of the verb phrase is missing – 'Animal food' [is] 'broken down in respiration' – as is the verbal link to carbon dioxide – [releasing?] 'carbon dioxide':

2	Noun phrase/subject	Verb phrase with object	Noun phrase/subject
	'Animal food'	'Broken down in respiration'	'Carbon dioxide'

Table A7.4: Node-connector-node combination 2 from figure A7.3.

Node-connector-node combination 3 applies a different verbal tactic, using only noun phrases, *ie,* subjects:

3	Noun phrase/subject	Noun phrase/subject	Noun phrase/subject
	'Carbon dioxide'	'Carbon assimilation and further synthesis in plants'	'Carbohydrates, Fats & protein'

Table A7.5: Node-connector-node combination 3 from figure A7.3.

Here the graphic syntax may help the interpretation of this verbal linkage, *eg,* 'Carbon assimilation and further synthesis in plants' [connects] 'Carbon dioxide' to 'Carbohydrates, Fats & Protein'.

Node-connector-node combination 4 again applies a verb phrase clause between first/second and second/third linked graphic objects, similarly excluding the explicit verbal link to the second node – 'Carbohydrates, Fats & Protein' [are] 'Eaten by animals':

4	Noun phrase/subject	Verb phrase with object	Noun phrase/subject
	'Carbohydrates, Fats & Protein'	'Eaten by animals'	'Animal food'

Table A7.6: Node-connector-node combination 4 from figure A7.3.

Finally, the fifth node-connector-node combination reflects the third one, applying only subjects. Here the inconsistency is further increased by the unlabelled arrow.

5	Noun phrase/subject	-	Noun phrase/subject
	'Carbohydrates, Fats & Protein'	-	'Plant tissues'

Table A7.7: Node-connector-node combination 5 from figure A7.3.

Parts of the verbal syntax in this analysed diagram thereby encourages linear verbal reading within the nodes and connectors. This pattern is broken however, by the instances with inconsistent verbal syntax. The inconsistencies include, firstly, the omission of verbal elements thus 'breaking' the grammatical clauses which verbally link individual graphic objects. Secondly, when both noun phrase and verb phrase clauses are applied within the visual linking in the diagram, the positive redundancy is interrupted; the reader needs to reconsider the verbal relations for each node-connector-node combination. This diagram's verbal syntax thereby disregards the potential advantages of positive redundancy and increases the diagram's ambiguity about the nature and role of the content proper elements. This pattern continues when singling out other clause elements for analysis, such as inconsistent use of passive and active voice.

A7.4 Inconsistent passive and active voice

When focusing on the above analysed clauses, the use of grammatical voice in the verb phrases are of particular interest. Grammatical passive and active voices relate directly to the graphic syntax by deciding which of the text graphic objects function as grammatical agents within verbally linked text objects. This in turn relates to Richard's (1984) definition of noun and verb spaces within diagrams. A grammatical active voice determines whether the text object in a node or arrow is the grammatical agent. When using active voice, the first node in a node-arrow-node sequence is the grammatical agent. When passive voice is applied the arrow serves this role. This in turn determines the interrelations between the related content proper elements.

Node-connector-node combination 1, 2, and 4 are inter-consistent as they all apply verb phrases in the clauses. Closer scrutiny reveals inconsistent use of voice, however:

1] 'Animal tissues' 'decay on death of animal' is active voice.

2] If assuming the addition of 'is' in 'Animal food' [is] broken down in respiration' then this clause is passive voice,

4] as is 'Carbohydrates, Fats & Protein' [are] 'eaten by animals'.

This difference in voice creates ambiguity, due to the node being the grammatical active agent in example 1, whereas the arrow labels are grammatical active agents in example 2 and 4. In relation to the content proper, this creates confusion about the active or passive role played by the cycle's elements. The ambiguity about these roles is further increased when the use of prepositions is inconsistent.

A7.5 Inconsistent prepositions

A preposition 'expresses a relationship of meaning between two parts of a sentence, most often showing how the two parts are related in time and space.' (Crystal, 2003: 188). Prepositions thereby have an interesting effect on the graphic and verbal syntax relation, by indicating relations between information types within a single text object and, in turn, implicit interrelations within and between nodes and connectors. This was previously indicated when discussing the coding values for 'multiple information types *eg*, 'photosynthesis in plants' [sections 4.4.1.7 and 5.2.2.3]. Scrutinising the prepositions in the clauses extracted from figure A7.3, for example, reveals four different verbal relations between chemical transformation processes in the cycles:

	Visual/verbal tactic: **Connector/verb space** ⟶	**Content proper:** **Information categories**
1	Decay *on* death *of* animal	*Temporal sequence of processes*: Chemical transformation taking place after another biological process.
2	Broken down *in* respiration	*Simultaneous processes*: Chemical transformation taking place within/during another biological process.
3	Carbon assimilation and further synthesis *in* plants	*Simultaneous processes within one element*: Chemical transformations taking place inside an organism.
4	Eaten *by* animals	*Processes by agent*: [Animal food] Transferred into organism/organism agent for process.

Table A7.8: Use of prepositions and the resulting content proper message.

This analysis demonstrates how the preposition in an individual node or arrow label further affects any verbally or visually linked graphic object; creating several, visually implicit interrelations. In turn this affects the message about the content proper elements' relations in space and time. The inconsistency found in figure A7.3 is particularly concerning, given that these clauses derive from the arrow labels only. The complication increases when the verbal and visual linking to text objects in the nodes is considered. In the node-connector-node combination 1, for example, the first node represents material. The arrow represents a chemical transformation currently taking place as well as a biological process, or event, that has taken place before the current one. The second node indicates matter which has been both transformed and transferred.

1	'Animal tissues'	'Decay on death of animal'	'Carbon dioxide'
	Material	Chemical *transformation* of material taking place after another biological process	Material now *transformed* into Carbon dioxide and matter *transferred* to atmosphere

Table A7.9: use of prepositions and resulting information categorisation in figure A7.3

In the physical reality of a carbon cycle, it is the respiration of decomposing bacteria that transforms oxygen into carbon dioxide – an additional and implicit process located inside the agents of the explicit decay process. As such, three parallel processes are implicit within one visual arrow: decay, bacteria respiration, and release of carbon dioxide. This analysed diagram, however, appears to explain that animal tissue is transformed into carbon dioxide.

Node-connector-node combination 4 presents particularly ambiguous verbal linking between the nodes and arrow labels:

4	'Carbohydrates, Fats & protein'	'Eaten by animals'	'Animal food'
	Matter	Matter *transferred* into organism/organism agent for process	Matter now *transformed* into material and possible *stored* within the animal

Table A7.10: use of prepositions and resulting information categorisation in figure A7.3

The relation between the content proper elements is here unclear. Does 'Carbohydrates, Fats & Protein' become 'animal food' once it has transferred into the animal? Does 'animal food' represent 'carbohydrates…' stored in the digestive system? Or is 'animal food' in reality another name for 'carbohydrates…'? In which case the two graphic objects – hence related content proper elements – are synonymous?

A similar ambiguity occurs in node-arrow-node combination 5, due to the unlabelled arrow connecting 'Carbohydrates, Fats & Protein' and 'plant tissues'. This indicates movement, hence transfer of 'Carbohydrates, Fats & Protein' inside the plant.

5	'Carbohydrates, Fats & protein'	-	'Plant tissues'
	Matter	[Movement and direction]	Material *stored* within the plant

Table A7.11: Use of prepositions and resulting information categorisation in figure A7.3.

The first two of the node-connector-node combinations just demonstrated [tables A7.9 and A7.10] indicate transformation of matter and transfer from an organism to the atmosphere, *eg,* 'animal tissue'/'decay on death of animal'/'Carbon dioxide'. The latter node-connector-node combination [table A7.11] is, in the content proper context a physical movement taking place inside a plant. This difference in physical relation between the content proper elements is implicit in the graphic syntax, creating an ambiguous content proper message.

Presenting parts of this analysis in a table illustrates an interesting point about the information categorisation challenge posed by the ecological cycle content proper. Similarly to a table, a network diagram offers the designer a set of connected 'cells', *ie,* nodes and arrows. The information just analysed highlights the challenge to potentially accommodate five information types – organism, process (simultaneous transfer and transformation), process agent, and matter – within two types of graphic objects. Several more table cells/graphic objects are thereby needed to accommodate such information with increased visual clarity, *eg,* the process, the agent, and the input/output could be distinctively categorised.

When viewed together the just outlined four verbal syntax tactics elucidate several advantages about considering a diagram's verbal syntax. This aspect may, *eg,* provide verbal linking to emphasise the visual linking or increase the detail of spatial and temporal relations within single text objects, *ie,* content proper elements. If used ineffectively, however, the found verbal syntax tactics may complicate the reader's experience significantly. This is demonstrated in the following summarising overview.

A7.6 Overview of verbal and graphic syntax interaction findings

Figure A7.4 illustrates all four verbal syntax tactics identified through this research enquiry: verbal syntax linear linked between graphic objects, noun and verb phrases, passive and active voice, and prepositions. The verbal syntax includes nouns derived from a verb, nouns, verbs, and adverbs. Seven different interactions between verbal and graphic syntax can be found in this diagram as listed below; the reference numbers here indicate node-connector-node sequences.

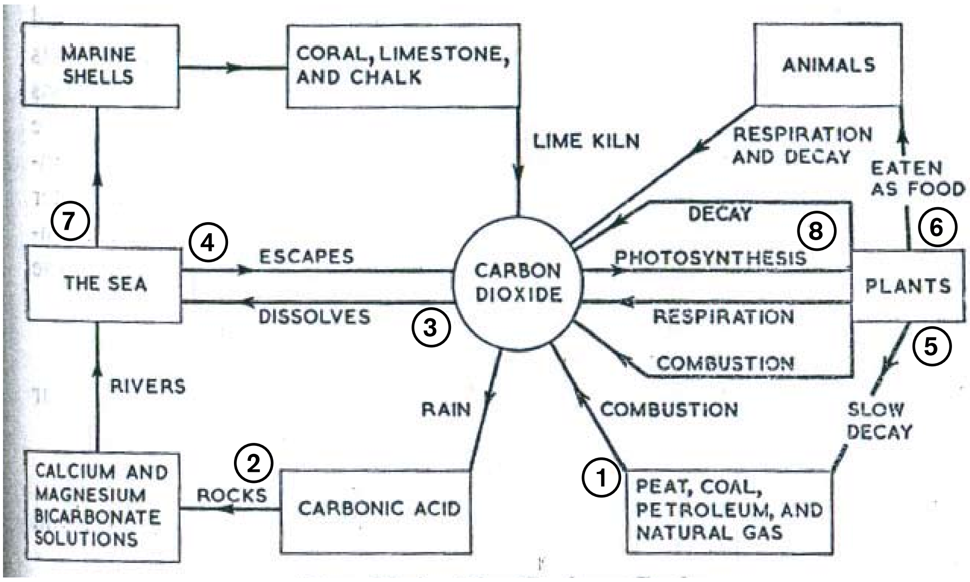


Figure A7.4 / Diagram no 080

Graphic syntax aspect highlighted
Overview of verbal and graphic syntax interaction findings

The carbon cycle
From: Hicks (1970: 405)

1. 'Carbon dioxide', 'combustion', 'peat, coal…': graphic syntactic conceptual linking and omits verbal linkage.
2. 'Carbonic acid', 'rocks', 'calcium and magnesium…': assuming that 'rocks' is a plural noun, rather than verb, then 'rocks' is a conceptual link, or rocks move from 'carbonic acid' to 'calcium and magnesium…'. The ambiguous verbal linking appears unintended.
3. 'Carbon dioxide' 'dissolves' 'the sea': a verb phrase is created by applying an active voice verb 'dissolves'. 'Carbon dioxide' is a grammatical subject, 'the sea' its object. In reality, it is the matter that dissolves when absorbed by the water.

4. Meanwhile 'the sea' 'escapes' 'carbon dioxide'. A puzzling verbal combination, even if 'the sea' is now the grammatical subject and 'carbon dioxide' the object.
5. 'Plants' 'slow decay' 'peat, coal…': introduces a temporal feature to the visual arrow. The linear verbal linkage has 'plants' as grammatical subjects and 'peat, coal…' as grammatical objects. In reality the plants are transformed through fossilisation into the fossil fuels.
6. 'Plants' 'eaten as food' 'animals'. Here the passive voice results in the second node being the grammatical agent, A transfer takes place between the content proper elements in each node.

The consequence in diagram A7.4 is that the two graphic syntactic roles – nodes and connectors – accommodate six different types of verbal linking, in addition to the explicit visual linking. This visual linking further includes unlabelled arrows, indicating movement of content proper elements in one node towards the next [7]. If read as such, 'the sea' moves towards 'marine shells'. This diagram thereby includes all four ineffective graphic tactics for verbal syntax identified in this research enquiry. In addition to these ambiguities, the physical positioning of arrows and their labels between 'carbon dioxide' and 'plants' [8] creates the visual illusion of a node.

In this thesis, the discussion of verbal syntax serves as an additional demonstration of how information may be categorised using graphic syntax. Only four verbal syntax aspects have been discussed, leaving several other themes to explore in future research. Such research could investigate qualitatively, in-depth, how verbal and graphic syntax interact, and an instructional science focus could measure the user experience of different tactics. This particular junction of verbal and graphic syntax within diagrams is fairly unexplored in existing research. Reviewed literature concentrate on comparing visual and verbal syntax *eg,* discussion of how closely they may be compared (*eg,* Twyman, 1979; Richards, 1984; Engelhardt, 2002; Gillieson, 2008). These discussions do not shine light on direct and practical relations between labels and textual objects within diagrams. Other sources focus on the graphic object-to-object relations and on the physical integration of words and pictures within diagrams, *ie,* compositional issues (*eg,* Tufte, 2006; Horn, 1999) or between diagrams and captions (Schriver, 1997).

Appendix 8

Demonstration of table 5.1 [section 5.8.1] as check list for identifying ineffective graphic tactics

Figure A8.1 is here analysed using the list of ineffective graphic tactics presented in chapter 5. This demonstrates how practitioners may use the table as a checklist for identifying ineffective graphic tactics in ecological cycle network diagrams. The interrelations between the ineffective graphic tactics found in this diagram are discussed in chapter 5 [section 5.8.1.2].

Starting by identifying what is shown, figure A8.1 is an open looped network diagram with beginning [a] and end points [a, b, c]. Node [a] here serve as both a beginning and end point, due to the arrow [d] having two heads and no tail. The diagram further includes three puzzling instances of nodes and connector combinations; three nodes have outgoing arrows only, no incoming [e, f, g]. These graphic tactics are excluded as general indicators of graphic tactics in this thesis because they were only found in this single example.

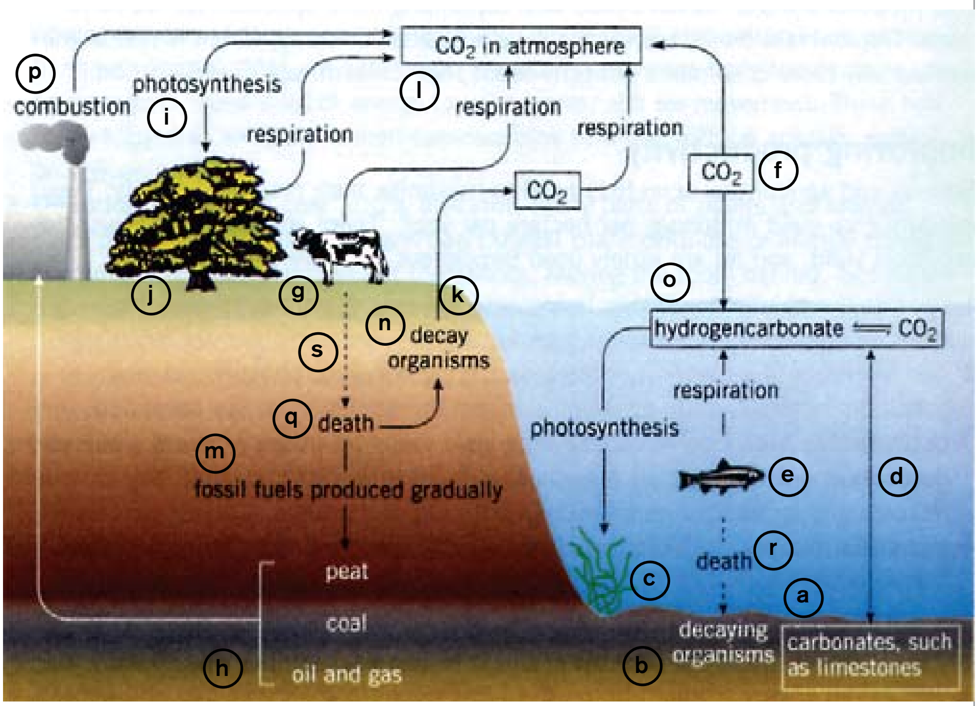


Figure A8.1: Diagram no 188

The carbon cycle
From: Graham and Lewis (2001: 140)

Ineffective graphic tactic		Example in figure A8.1
Coding variable 1 – node and connector syntactic roles		
1	Implicit nodes: Branching arrow Section [4.4.1.1 / 5.2.2.1]	n/a
2	Implicit nodes: Merging arrows Section [4.4.1.2 / 5.2.2.1]	The node [h] is half contained, by an arrow tail forming a bracket.
3	Implicit nodes: Arrow-arrow connection Section [4.4.1.3 / 5.2.2.1]	n/a
4	Implicit nodes: Intersecting arrows Section [4.4.1.4 / 5.2.2.1]	n/a
5	Imprecise nodes/arrow labels: Imprecise relative spatial positioning [Section 4.4.1.5 / 5.2.2.1]	Arrow labels [*eg,* i] interrupt the arrow shafts, may be confused with nodes.
6	Explicit nodes: Unlabelled pictorial object [Section 4.4.1.6 / 5.2.2.2]	The water plant [c], the fish [e], the cow [g], and the tree [j].
7	Explicit connectors: Unlabelled arrow [Section 4.4.1.6 / 5.2.2.2]	8 instances, *eg,* [k].
8	Explicit nodes and connectors: Multiple information types – polysemic [Section 4.4.1.7 / 5.2.2.3]	Nodes: Multiple information types – polysemic [l, o]. Connectors: Multiple information types – monosemic [m].
9	Categorising organisms in connector roles [Section 4.4.1.6 / 5.2.3.1]	n/a.
10	Explicit connectors: Excluding matter from connector roles [Section 4.4.1.6 / 5.2.3.2]	Matter appears in nodes only, *eg,* [f].
11	Explicit connectors: Process in connector roles [Section 4.4.1.6 / 5.2.3.3]	Photosynthesis [i] appears outside the tree [j].
12	Exclusively unlabelled arrows [Section 4.4.1.6 / 5.2.3.4]	n/a.

Ineffective graphic tactic		Example in figure A8.1
13	Polysemy within a syntactic role [Section 4.3.1.7 / 5.2.3.4]	Visually similar nodes: · Pictorial objects: *process* 'combustion' [p] and unlabelled [j]. · Contained nodes, black: *matter* 'CO_2' [f] and 'multiple information types – polysemic' [l, o]. · Uncontained nodes - white type: *organisms* 'decaying organisms' [b] and *material* 'peat, coal, oil and gas' [h]. · Uncontained nodes black type: *process* 'death' [q] and *organisms*, 'decay organisms' [n] Visually similar connectors: · Regular, black arrows: *process* 'photosynthesis' [i] and 'multiple information types – monosemic' [m] · Dashed black arrows: *process* 'death' [r] and unlabelled [r, s] Analysis within nodes and connectors is excluded from this research enquiry, however, here the *process* 'death' appears in both nodal [q] and connector roles [r].
Coding variable 2 –pictorial object labels		
14	Text image relationship inconsistent [Section 4.4.2.1 / 5.3.2.1]	Intermediate referents [p] and unlabelled pictorial objects [j].
15	Polysemic pictorial objects [Section 4.4.2.1 / 5.3.3.1]	See ineffective graphic tactic 12, polysemic nodes.
Coding variable 3 – arrow types		
16	Polysemic arrow types [Section 4.4.3 / 5.4.2.1]	Visually similar connectors: · Regular, black arrows: conceptual link 'photosynthesis' [i] and 'multiple information types – monosemic', which included *material*, *process* and temporal aspect [m]. · Dashed black arrows: conceptual link 'death' [r] and unlabelled, *ie,,* potentially movement of source [r, s].
Coding variable 4 – visual attributes		
17	Nominal visual attributes: Inconsistent shape [Section 4.4.4.1 / 5.5.2.1]	Nodes: Visually similar black container shapes include matter, 'CO_2' [f] and 'multiple information types – polysemic' [l, o].
18	Nominal visual attributes: Inconsistent colour within syntactic role [Section 4.4.4.1 / 5.5.2.2]	Colour appears decided by background illustration, rather than information categories. Nodes: White container: 'multiple information types – monosemic' [a]. Black containers: inconsistent, [see above ineffective graphic tactic 17]. Arrows: Black arrows are polysemic [see ineffective graphic tactic 12 and 16], white arrow is unlabelled.

Ineffective graphic tactic		Example in figure A8.1
19	Nominal visual attributes: Inconsistent colour *between* syntactic roles [Section 4.3.4.1 / 5.2.4.2]	White arrow and white container associate implicit information and 'multiple information type – monosemic' [a].
20	Ordinal visual attributes: Inconsistent texture [Section 4.4.4.2 / 5.5.2.3]	Dashed arrows include implicit information [s] and *process* [r].
21	Quantitative visual attributes: Inconsistent size [Section 4.4.4.3 / 5.5.2.4]	Size of container shapes appear decided by amount of text.
Coding variable 5 – typographic attributes		
22	Nondistinctive nodes and arrow labels [Section 4.4.5.1 / 5.6.1.1]	Text nodes [q], pictorial label [p] and arrow labels [i] are nondistinctive.
Coding variable 6 – Verbal syntax		
23	Inconsistent verbal syntax in nodes [Section 4.4.6.1 / 5.7.2.1]	Hinders positive redundancy when reading diagram; ambiguity about nature of connected elements.
24	Inconsistent verbal syntax in arrow labels [Section 4.4.6.1 / 5.7.2.1]	Hinders positive redundancy when reading diagram; ambiguity about nature of connecting elements.
25	Noun in arrow labels [Section 4.4.6.1 / 5.7.3.1]	May result in reading a 'movement between' arrow type and chemical transformation instead of transfer.
Verbal and graphic syntax interactions [appendix 7]		
26	Inconsistent linear verbal link within graphic objects [Appendix 7]	n/a.
27	Inconsistent noun and verb phrases [Appendix 7]	Include 'decay organisms' [n] and 'decaying organisms' [b]
28	Inconsistent passive and active voice [Appendix 7]	'Fossil fuels produced gradually' [m]; fossil fuels appear to be produced from 'death' [q] [explained in detail following this table]
29	Inconsistent prepositions [Appendix 7]	'CO_2' [f] appears, visually, in the middle of the atmosphere before verbally appearing as 'CO_2 in atmosphere' [l]

Figure A8.1 includes 23 of the 29 ineffective graphic tactics identified in this research enquiry. The interrelations between these ineffective graphic tactics, and the effects on the content proper message are discussed in section 5.8.1.1.

Appendix 9
Identification of ineffective graphic tactics in Danish data set.

The geographical scope of this research enquiry extends to Denmark and the current market for science textbooks for 14-18 year age groups. Four ecological cycle network diagrams from publications currently on the Danish market are analysed here using the coding scheme and table 5.1 [section 5.8.1].

A9.1 Danish example 1

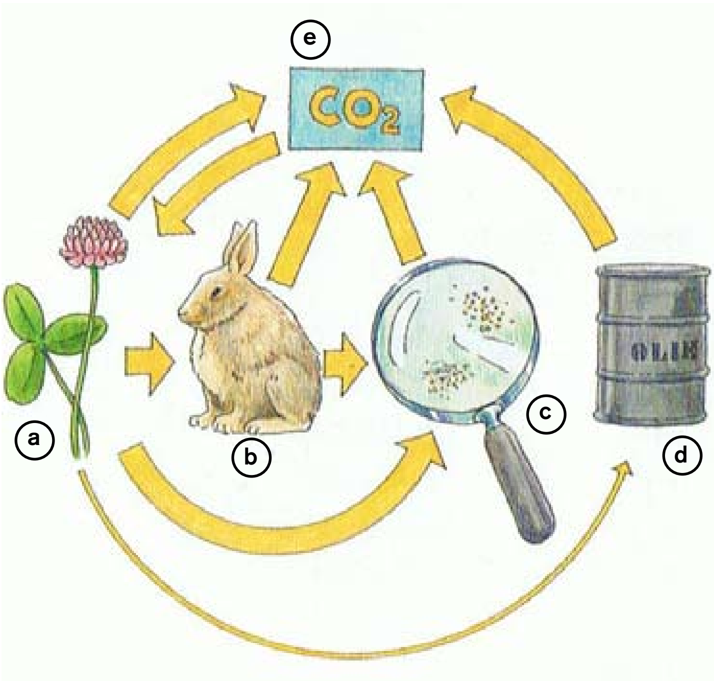


Figure A9.1: Diagram no 246

Kulstofskredsløb
From: Bruun (2008: 205)

Ineffective graphic tactic		Example in figure A9.1
Coding variable 1 – node and connector syntactic roles		
1	Implicit nodes: Branching arrow Section [4.4.1.1 / 5.2.2.1]	n/a.
2	Implicit nodes: Merging arrows Section [4.4.1.2 / 5.2.2.1]	n/a.

Ineffective graphic tactic		Example in figure A9.1
3	Implicit nodes: Arrow-arrow connection Section [4.4.1.3 / 5.2.2.1]	n/a.
4	Implicit nodes: Intersecting arrows Section [4.4.1.4 / 5.2.2.1]	n/a.
5	Imprecise nodes/arrow labels: Imprecise relative spatial positioning.[Section 4.4.1.5 / 5.2.2.1]	n/a.
6	Explicit nodes: Unlabelled pictorial object [Section 4.4.1.6 / 5.2.2.2]	Four instances: Plant [a], rabbit [b], magnifying glass with bacteria [c], oil barrel [d].
7	Explicit connectors: Unlabelled arrow [Section 4.4.1.6 / 5.2.2.2]	See ineffective tactic no. 12.
8	Explicit nodes and connectors: Multiple information types – polysemic [Section 4.4.1.7 / 5.2.2.3]	n/a.
9	Categorising organisms in connector roles [Section 4.4.1.6 / 5.2.3.1]	n/a.
10	Explicit connectors: Excluding matter from connector roles [Section 4.4.1.6 / 5.2.3.2]	*Matter* appears only in nodal position [e] 'CO_2'.
11	Explicit connectors: Process in connector roles [Section 4.4.1.6 / 5.2.3.3]	n/a.
12	Exclusively unlabelled arrows [Section 4.4.1.6 / 5.2.3.4]	All arrows are unlabelled.
13	Polysemy within a syntactic role [Section 4.3.1.7 / 5.2.3.4]	Pictorial nodes are polysemic: Three are unlabelled [a-c] one indicates 'oil'/'olie', *ie, material.* Connectors are polysemic due to omission of arrow labels.
Coding variable 2 –pictorial object labels		
14	Text image relationship inconsistent [Section 4.4.2.1 / 5.3.2.1]	n/a.
15	Polysemic pictorial objects [Section 4.4.2.1 / 5.3.3.1]	Pictorial objects are polysemic, See ineffective tactic no. 13.
Coding variable 3 – arrow types		

Ineffective graphic tactic		Example in figure A9.1
16	Polysemic arrow types [Section 4.4.3 / 5.4.2.1]	Arrow types are polysemic due to omission of arrow labels. See ineffective tactic no. 13.
Coding variable 4 – visual attributes		
17	Nominal visual attributes: Inconsistent shape [Section 4.4.4.1 / 5.5.2.1]	n/a.
18	Nominal visual attributes: Inconsistent colour within syntactic role [Section 4.4.4.1 / 5.5.2.2]	n/a.
19	Nominal visual attributes: Inconsistent colour *between* syntactic roles [Section 4.3.4.1 / 5.2.4.2]	n/a.
20	Ordinal visual attributes: Inconsistent texture [Section 4.4.4.2 / 5.5.2.3]	n/a.
21	Quantitative visual attributes: Inconsistent size [Section 4.4.4.3 / 5.5.2.4]	The size attribute applied to arrows is inconsistent, due to the omission of arrow labels.
Coding variable 5 – typographic attributes		
22	Nondistinctive nodes and arrow labels [Section 4.4.5.1 / 5.6.1.1]	n/a.
Coding variable 6 – Verbal syntax		
23	Inconsistent verbal syntax in nodes [Section 4.4.6.1 / 5.7.2.1]	n/a.
24	Inconsistent verbal syntax in arrow labels [Section 4.4.6.1 / 5.7.2.1]	n/a.
25	Noun in arrow labels [Section 4.4.6.1 / 5.7.3.1]	n/a.
Verbal and graphic syntax interactions [appendix 7]		
26	Inconsistent linear verbal link within graphic objects [Appendix 7]	n/a.
27	Inconsistent noun and verb phrases [Appendix 7]	n/a.
28	Inconsistent passive and active voice [Appendix 7]	n/a.
29	Inconsistent prepositions [Appendix 7]	n/a.

A9.2 Danish example 2

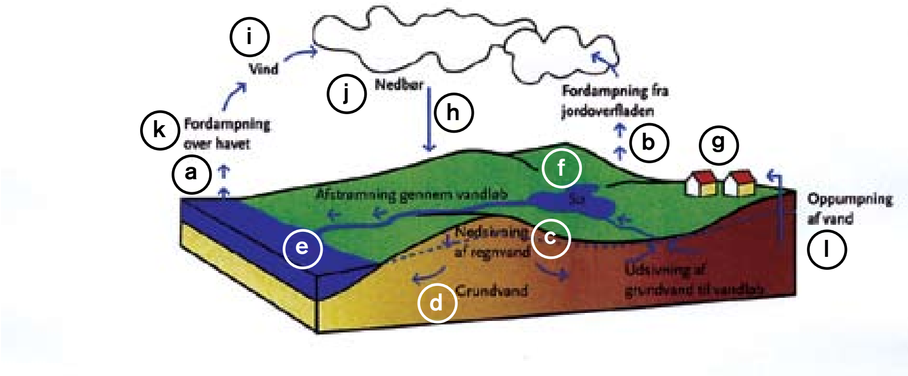


Figure A9.2 Diagram no 223

Vandets kredsløb
From: Egebo *et al* (2005: 129).

Ineffective graphic tactic		**Example in figure A9.2**
Coding variable 1 – node and connector syntactic roles		
1	Implicit nodes: Branching arrow Section [4.4.1.1 / 5.2.2.1]	n/a.
2	Implicit nodes: Merging arrows Section [4.4.1.2 / 5.2.2.1]	n/a.
3	Implicit nodes: Arrow-arrow connection Section [4.4.1.3 / 5.2.2.1]	[a] and [b] possible indicates evaporation.
4	Implicit nodes: Intersecting arrows Section [4.4.1.4 / 5.2.2.1]	n/a.
5	Imprecise nodes/arrow labels: Imprecise relative spatial positioning [Section 4.4.1.5 / 5.2.2.1]	'nedsivning af regnvand'/'leaching' [c] 'grundvand'/'ground water' [d] 'nedbør'/'rain' [j]
6	Explicit nodes: Unlabelled pictorial object [Section 4.4.1.6 / 5.2.2.2]	Pictorial sea node unlabelled [e] Pictorial houses unlabelled [g]
7	Explicit connectors: Unlabelled arrow [Section 4.4.1.6 / 5.2.2.2]	7 unlabelled arrows *eg*, [h]
8	Explicit nodes and connectors: Multiple information types – polysemic [Section 4.4.1.7 / 5.2.2.3]	n/a.

Ineffective graphic tactic		Example in figure A9.2
9	Categorising organisms in connector roles [Section 4.4.1.6 / 5.2.3.1]	n/a.
10	Explicit connectors: Excluding matter from connector roles [Section 4.4.1.6 / 5.2.3.2]	Matter is excluded from connector roles.
11	Explicit connectors: Process in connector roles [Section 4.4.1.6 / 5.2.3.3]	n/a.
12	Exclusively unlabelled arrows [Section 4.4.1.6 / 5.2.3.4]	n/a.
13	Polysemy within a syntactic role [Section 4.3.1.7 / 5.2.3.4]	Nodes are polysemic. Regular text objects: *Energy* 'vind'/'wind' [i] and 'multiple information types – monosemic' [*eg,* c] Pictorial objects: *Material* 'nedbør'/'rain' [j], 'multiple information types – monosemic' [*eg,* b], and *pool* 'sø'/lake. Connectors are polysemic. Unlabelled, *eg,* [h] and 'multiple information types – monosemic'.
Coding variable 2 –pictorial object labels		
14	Text image relationship inconsistent [Section 4.4.2.1 / 5.3.2.1]	Intermediate referent *eg,* 'gundvand'/'ground water'[d] and intended referent 'sø'/lake [f]
15	Polysemic pictorial objects [Section 4.4.2.1 / 5.3.3.1]	See ineffective tactic no. 13.
Coding variable 3 – arrow types		
16	Polysemic arrow types [Section 4.4.3 / 5.4.2.1]	Unlabelled [h] and 'multiple information types – monosemic'.
Coding variable 4 – visual attributes		
17	Nominal visual attributes: Inconsistent shape [Section 4.4.4.1 / 5.5.2.1]	n/a.
18	Nominal visual attributes: Inconsistent colour within syntactic role [Section 4.4.4.1 / 5.5.2.2]	n/a.
19	Nominal visual attributes: Inconsistent colour *between* syntactic roles [Section 4.3.4.1 / 5.2.4.2]	n/a.
20	Ordinal visual attributes: Inconsistent texture [Section 4.4.4.2 / 5.5.2.3]	n/a.

Ineffective graphic tactic		Example in figure A9.2
21	Quantitative visual attributes: Inconsistent size [Section 4.4.4.3 / 5.5.2.4]	n/a.
Coding variable 5 – typographic attributes		
22	Nondistinctive nodes and arrow labels [Section 4.4.5.1 / 5.6.1.1]	No typographic distinction.
Coding variable 6 – Verbal syntax		
23	Inconsistent verbal syntax in nodes [Section 4.4.6.1 / 5.7.2.1]	Nouns [f] and verb phrases, *eg*, [c].
24	Inconsistent verbal syntax in arrow labels [Section 4.4.6.1 / 5.7.2.1]	Check this one.
25	Noun in arrow labels [Section 4.4.6.1 / 5.7.3.1]	n/a.
Verbal and graphic syntax interactions [appendix 7]		
26	Inconsistent linear verbal link within graphic objects [Appendix 7]	n/a.
27	Inconsistent noun and verb phrases [Appendix 7]	‘fordampning over havet’/‘evaporation above the sea’ [k] linked to ‘vind’/’wind’ [i]
28	Inconsistent passive and active voice [Appendix 7]	n/a.
29	Inconsistent prepositions [Appendix 7]	All ‘multiple information type’ coding values include different prepositions, *eg*, ‘over’/’above’ [k], ‘fra’/’from’ [l], ‘af’/’of’ [c],

A9.3 Danish example 3

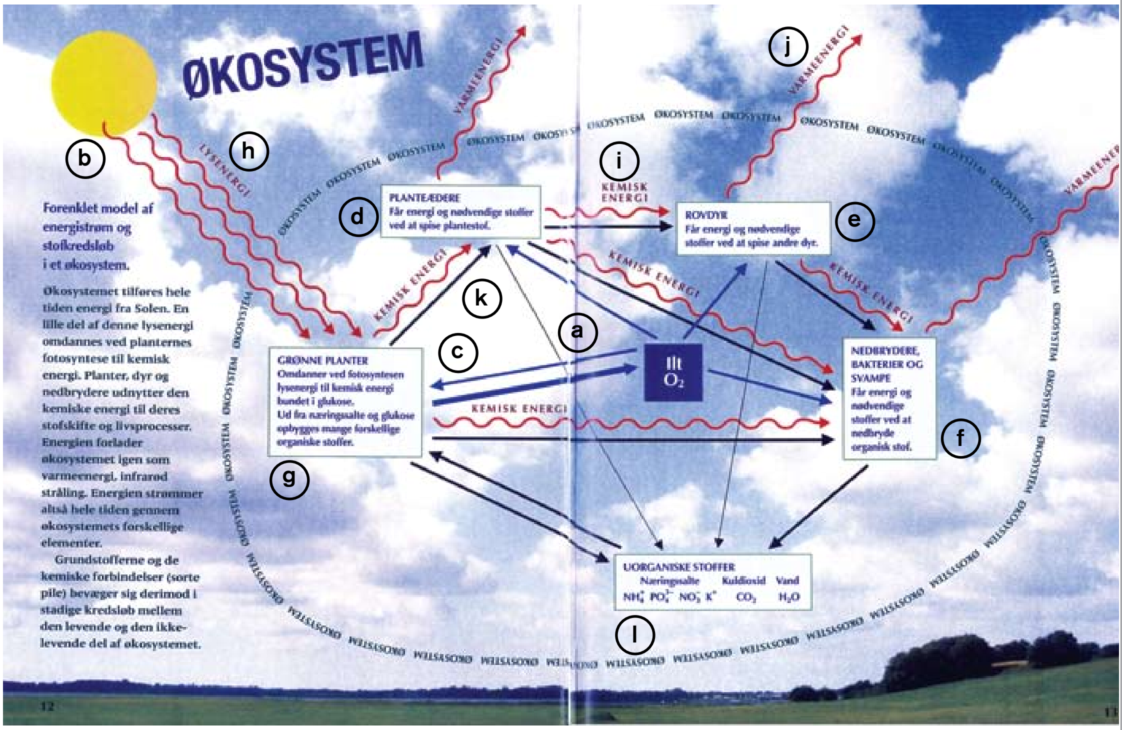


Figure A9.3: Diagram no. 234

Økosystem
From: Bjerrum *et al* (2005: 12-13)

Ineffective graphic tactic		Example in figure A9.3
Coding variable 1 – node and connector syntactic roles		
1	Implicit nodes: Branching arrow Section [4.4.1.1 / 5.2.2.1]	n/a.
2	Implicit nodes: Merging arrows Section [4.4.1.2 / 5.2.2.1]	n/a.
3	Implicit nodes: Arrow-arrow connection Section [4.4.1.3 / 5.2.2.1]	n/a.
4	Implicit nodes: Intersecting arrows Section [4.4.1.4 / 5.2.2.1]	*eg,* [a].
5	Imprecise nodes/arrow labels: Imprecise relative spatial positioning [Section 4.4.1.5 / 5.2.2.1]	n/a.
6	Explicit nodes: Unlabelled pictorial object [Section 4.4.1.6 / 5.2.2.2]	The pictorial sun is unlabelled [b].

Ineffective graphic tactic		Example in figure A9.3
7	Explicit connectors: Unlabelled arrow [Section 4.4.1.6 / 5.2.2.2]	Blue arrows and black arrows are unlabelled. Black arrow meaning is mentioned in body text as 'grundstof og kemiske forbindelser'/'matter and chemical transformations', *eg*, [c]
8	Explicit nodes and connectors: Multiple information types – polysemic [Section 4.4.1.7 / 5.2.2.3]	Nodes: Three contained nodes include '*organism* receive…' [d] [e] [f] and are 'multiple information types monosemic', one contained node include 'plants transform…' [g].
9	Categorising organisms in connector roles [Section 4.4.1.6 / 5.2.3.1]	n/a.
10	Explicit connectors: Excluding matter from connector roles [Section 4.4.1.6 / 5.2.3.2]	n/a.
11	Explicit connectors: Process in connector roles [Section 4.4.1.6 / 5.2.3.3]	n/a.
12	Exclusively unlabelled arrows [Section 4.4.1.6 / 5.2.3.4]	n/a.
13	Polysemy within a syntactic role [Section 4.3.1.7 / 5.2.3.4]	Contained nodes: See ineffective graphic tactic no. 8. Connectors: Blue arrows are unlabelled.
Coding variable 2 –pictorial object labels		
14	Text image relationship inconsistent [Section 4.4.2.1 / 5.3.2.1]	n/a.
15	Polysemic pictorial objects [Section 4.4.2.1 / 5.3.3.1]	Unlabelled sun [b].
Coding variable 3 – arrow types		
16	Polysemic arrow types [Section 4.4.3 / 5.4.2.1]	Blue arrows because they are unlabelled.
Coding variable 4 – visual attributes		
17	Nominal visual attributes: Inconsistent shape [Section 4.4.4.1 / 5.5.2.1]	Red arrows: Three sub-types of energy represented by same arrow shape, 'light energy'/'lysenergi' [h], 'chemical energy'/'kemisk energi' [i], and 'heat energy'/'varme energi' [j].
18	Nominal visual attributes: Inconsistent colour within syntactic role [Section 4.4.4.1 / 5.5.2.2]	Blue colour coding is inconsistent because arrows are unlabelled, blue node represents 'O_2'.
19	Nominal visual attributes: Inconsistent colour *between* syntactic roles [Section 4.3.4.1 / 5.2.4.2]	Blue colour coding is inconsistent because arrows are unlabelled.

Ineffective graphic tactic		**Example in figure A9.3**
20	Ordinal visual attributes: Inconsistent texture [Section 4.4.4.2 / 5.5.2.3]	n/a.
21	Quantitative visual attributes: Inconsistent size [Section 4.4.4.3 / 5.5.2.4]	Size of nodes appear decided by amount of text. Size between blue and black arrows: appears intended, but indicates equal quantities of implicit element [c] and chemical transformation [k].
Coding variable 5 – typographic attributes		
22	Nondistinctive nodes and arrow labels [Section 4.4.5.1 / 5.6.1.1]	n/a
Coding variable 6 – Verbal syntax		
23	Inconsistent verbal syntax in nodes [Section 4.4.6.1 / 5.7.2.1]	Verb phrases [d, e, f, g] and noun phrases, *eg,* [h].
24	Inconsistent verbal syntax in arrow labels [Section 4.4.6.1 / 5.7.2.1]	n/a
25	Noun in arrow labels [Section 4.4.6.1 / 5.7.3.1]	n/a.
Verbal and graphic syntax interactions [appendix 7]		
26	Inconsistent linear verbal link within graphic objects [Appendix 7]	n/a.
27	Inconsistent noun and verb phrases [Appendix 7]	See ineffective graphic tactic no. 3.
28	Inconsistent passive and active voice [Appendix 7]	n/a.
29	Inconsistent prepositions [Appendix 7]	n/a.

A9.4 Danish example 4

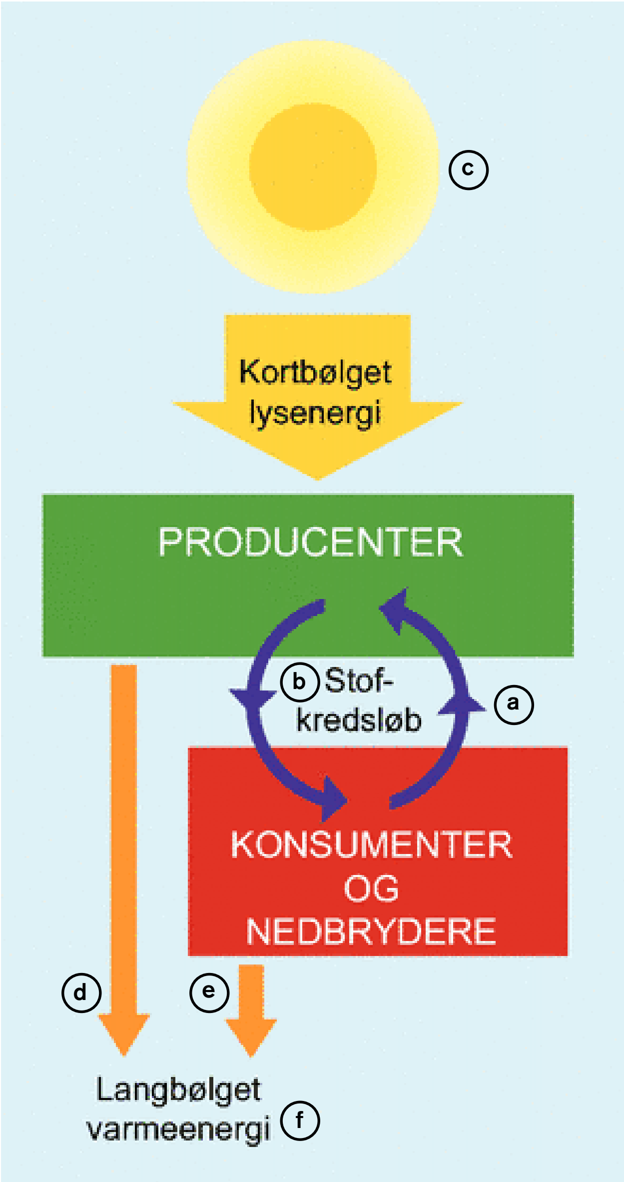


Figure A9.4 Diagram no 201

Stof og energi i fødenet
From: Sørensen *et al* (2008: 221)

Ineffective graphic tactic		Example in figure A9.4
Coding variable 1 – node and connector syntactic roles		
1	Implicit nodes: Branching arrow Section [4.4.1.1 / 5.2.2.1]	n/a.
2	Implicit nodes: Merging arrows Section [4.4.1.2 / 5.2.2.1]	n/a.
3	Implicit nodes: Arrow-arrow connection Section [4.4.1.3 / 5.2.2.1]	[a]

Ineffective graphic tactic		Example in figure A9.4
4	Implicit nodes: Intersecting arrows Section [4.4.1.4 / 5.2.2.1]	n/a.
5	Imprecise nodes/arrow labels: Imprecise relative spatial positioning [Section 4.4.1.5 / 5.2.2.1]	'stof kredsløb'/ matter cycle [b]
6	Explicit nodes: Unlabelled pictorial object [Section 4.4.1.6 / 5.2.2.2]	Pictorial sun [c]
7	Explicit connectors: Unlabelled arrow [Section 4.4.1.6 / 5.2.2.2]	[d] and [e]
8	Explicit nodes and connectors: Multiple information types – polysemic [Section 4.4.1.7 / 5.2.2.3]	n/a.
9	Categorising organisms in connector roles [Section 4.4.1.6 / 5.2.3.1]	n/a.
10	Explicit connectors: Excluding matter from connector roles [Section 4.4.1.6 / 5.2.3.2]	'stof kredsløb'/'matter cycle' [b], if read as a node, or caption within the arrows.
11	Explicit connectors: Process in connector roles [Section 4.4.1.6 / 5.2.3.3]	n/a.
12	Exclusively unlabelled arrows [Section 4.4.1.6 / 5.2.3.4]	n/a.
13	Polysemy within a syntactic role [Section 4.3.1.7 / 5.2.3.4]	Nodes: Regular type: 'stof kredsløb'/ matter cycle [b] and 'langbølget energi' / longwave energy [f]
Coding variable 2 –pictorial object labels		
14	Text image relationship inconsistent [Section 4.4.2.1 / 5.3.2.1]	n/a.
15	Polysemic pictorial objects [Section 4.4.2.1 / 5.3.3.1]	See ineffective graphic tactic no. 6, [c]
Coding variable 3 – arrow types		
16	Polysemic arrow types [Section 4.4.3 / 5.4.2.1]	Orange arrows are unlabelled [d and e].

Ineffective graphic tactic		Example in figure A9.4
Coding variable 4 – visual attributes		
17	Nominal visual attributes: Inconsistent shape [Section 4.4.4.1 / 5.5.2.1]	n/a.
18	Nominal visual attributes: Inconsistent colour within syntactic role [Section 4.4.4.1 / 5.5.2.2]	Orange arrows are unlabelled [d and e].
19	Nominal visual attributes: Inconsistent colour *between* syntactic roles [Section 4.3.4.1 / 5.2.4.2]	n/a.
20	Ordinal visual attributes: Inconsistent texture [Section 4.4.4.2 / 5.5.2.3]	n/a.
21	Quantitative visual attributes: Inconsistent size [Section 4.4.4.3 / 5.5.2.4]	n/a.
Coding variable 5 – typographic attributes		
22	Nondistinctive nodes and arrow labels [Section 4.4.5.1 / 5.6.1.1]	n/a.
Coding variable 6 – Verbal syntax		
23	Inconsistent verbal syntax in nodes [Section 4.4.6.1 / 5.7.2.1]	n/a.
24	Inconsistent verbal syntax in arrow labels [Section 4.4.6.1 / 5.7.2.1]	n/a.
25	Noun in arrow labels [Section 4.4.6.1 / 5.7.3.1]	n/a.
Verbal and graphic syntax interactions [appendix 7]		
26	Inconsistent linear verbal link within graphic objects [Appendix 7]	n/a.
27	Inconsistent noun and verb phrases [Appendix 7]	n/a.
28	Inconsistent passive and active voice [Appendix 7]	n/a.
29	Inconsistent prepositions [Appendix 7]	n/a.

Appendix 10
Interview sample variation: description of variation in professional experience

This appendix provides a description of the interviewees to supplement the formal phenomenographic sample variation [section 6.4]. The information is presented as a summary for each participant role, rather than individual interviewees, to retain anonymity.

Senior publishers/commissioning editors

The senior publishers interviewed have varied backgrounds. Three have a degree in natural science, followed by, respectively, a PHD in business, PHD in science, and an additional degree in Science Communication. Two mentioned running book shops, and one had progressed from publishing secretary to senior editor during her career. In contrast to these, one mentioned an art history degree and university lecturer/research background, before joining educational publishing.

Editors

Similarly to the senior publishers, the four editors represent a range of professional backgrounds, from 30 years as A-level teacher, to a PHD in science, a literature degree and a production editor.

Copy editors

No copy editors were interviewed, however their role was mentioned by the other participants.

Authors

All five authors interviewed where experienced authors, with a running working relationship with the publishers. Their author experience range from 6 years to 32 years, with a minimum of two publications. All authors have extensive practical teaching experience. Some are still active full-time, whereas others are limited to 4 hours per week. Most authors are active either as chief examiners in the UK [setting GCSE papers and mark scheme] or similarly involved in defining Common targets, as well as active in the

Association of Biology Teachers in Denmark.

Designers/illustrators

The two designers and two design managers interviewed represent a range of professional set ups. Two designers followed a traditional art school education and one now also works as associate lecturer at a design school. Another is self-taught, starting as a science author but gradually becoming more interested in the visual side of the textbooks, leading to a shift in professional focus. One illustrator started out working with window displays at department stores before concentrating on 2D illustrations.

Appendix 11
Standardised biological notation

The integration of research findings in chapter 7 revealed that part of the current information transformation rationale represents routine practice, regularly creating composites of existing diagram. An alternative to the current rationale is the option of embracing such routine practice, systemise it, and standardise it. This option is demonstrated by the 'Systems biology graphical notation' (Kitano, 2003; Kitano *et al*, 2005; Kohn and Aladjem, 2006; Le Novère *et al*, 2009) discussed in section [7.3.4]

Integrating a standardised biological notational system into the current visual output could ensure monosemy, by making explicit the meaning of each graphic object (Bertin, 1983). In particular, standardising pictorial objects would be helpful to address the relative high level of ambiguity found within this graphic syntax aspect by this research enquiry. Such system would pay homage to Otto Neurath's ISOTYPE (Neurath and Kinross, 2008), or standardised geographical mapping symbols (MacEachren, 2004). However, several obstacles exists for implementing such system at the current 14-18 years curriculum level. Firstly, the system would need implementation and consensus at a higher scientific level, before 'trickling down' to be included in the exam specifications aimed at the 14-18 years age groups. In relation to the 14-18 years age groups of readers, a trade-off for monosemy is the additional requirement of fluency in the particular graphic language. Secondly, and practically, such standardisation has to meet the technical needs of each publisher and the teaching requirement. The system proposed by Le Novère *et al* (2009) allows the publishers to preserve their visual autonomy, *eg* in relation to the overall aesthetics of each basic graphic shape. The room for manoeuvre for this expression is limited however by the interrelation of visual and typographic attributes. As an information design challenge and solution for monosemy, a standardised graphical notational system presents an interesting challenge. In practice it would prove hard to implement into current practice, in a 'bottom up' approach, *ie,* appearing from the professional practice context, before the scientific.

Figure 4.29: Coding variable 1: node and connector syntactic roles

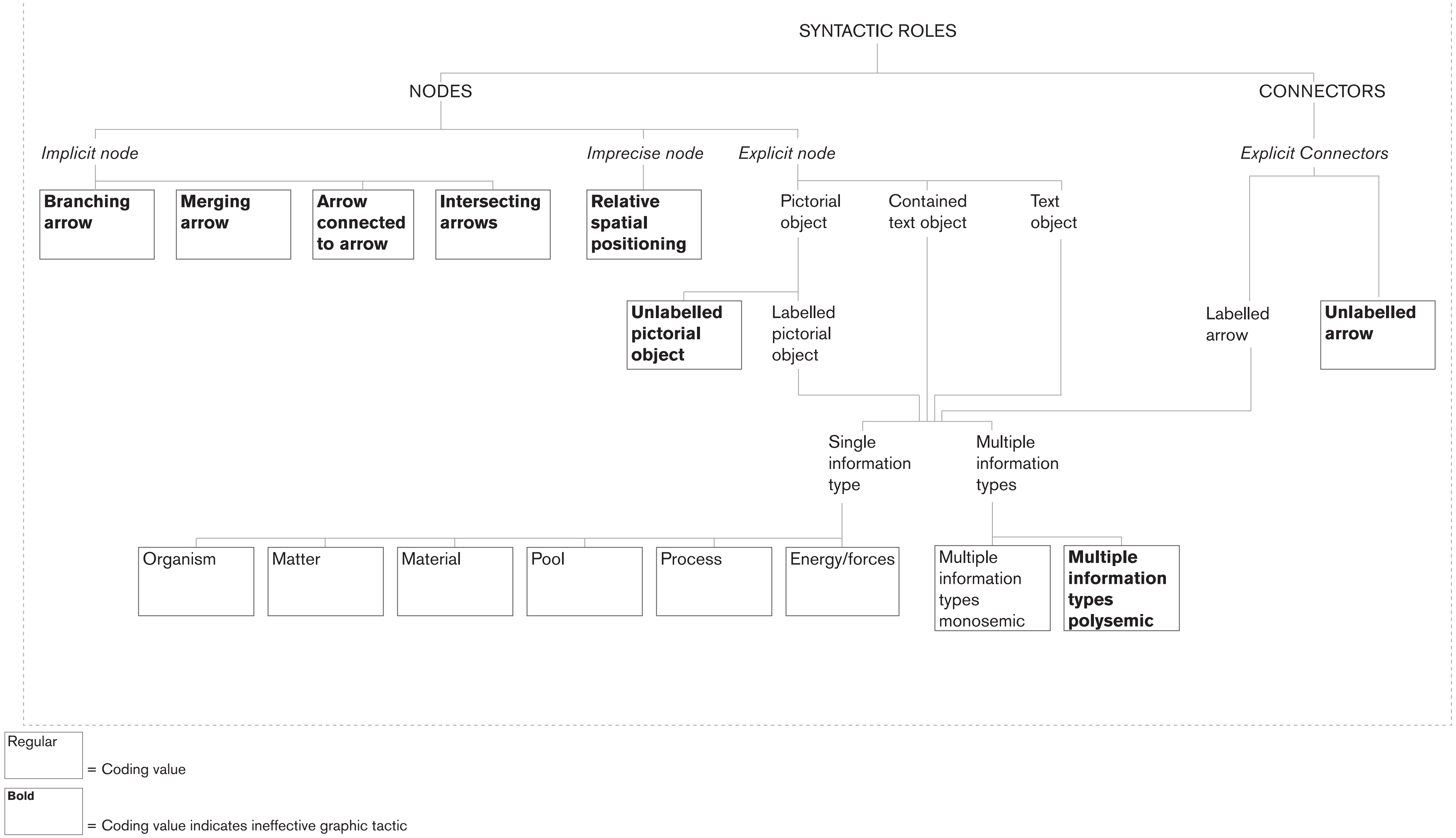


Figure 4.51: Complete coding scheme / design problem space

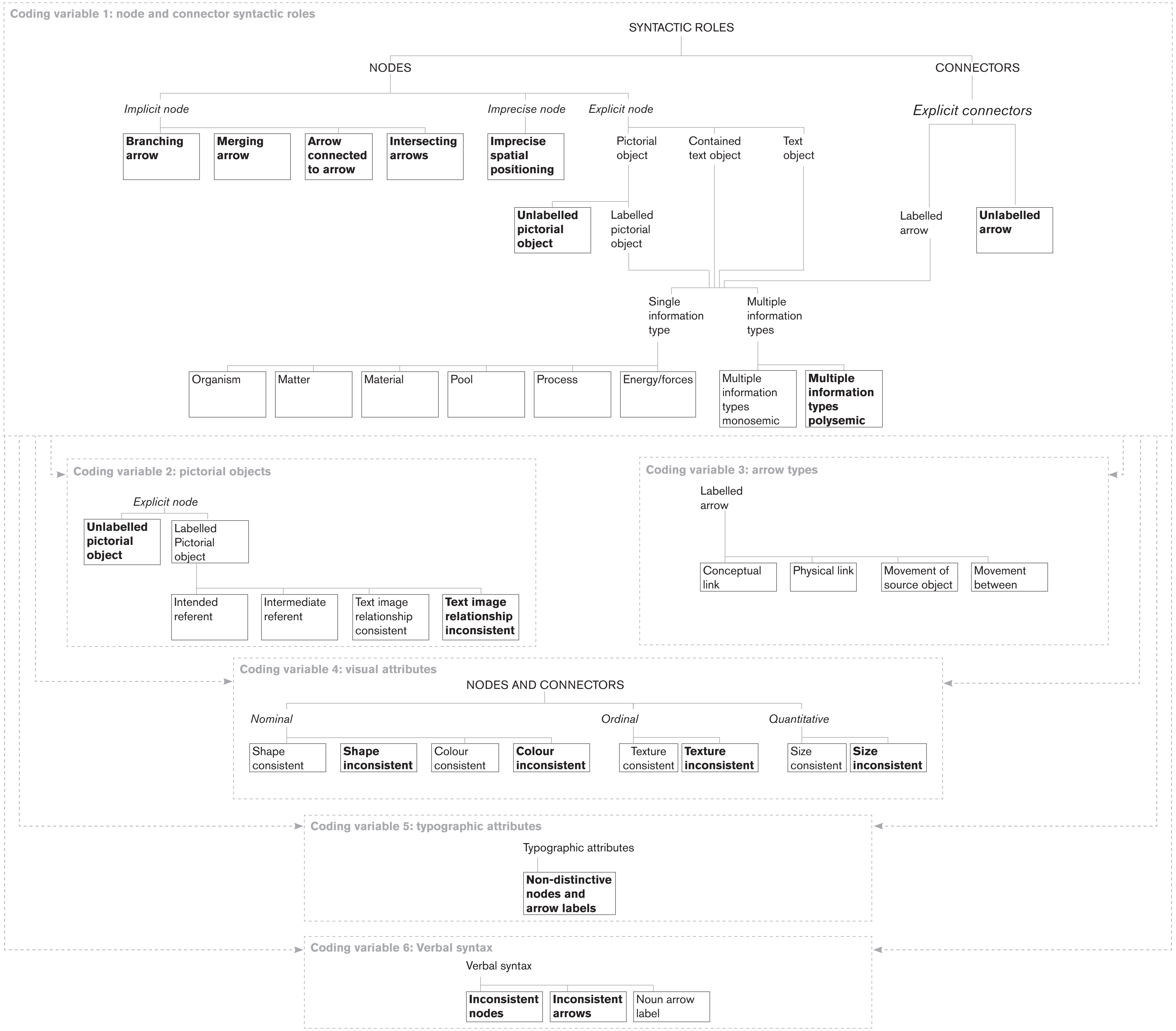
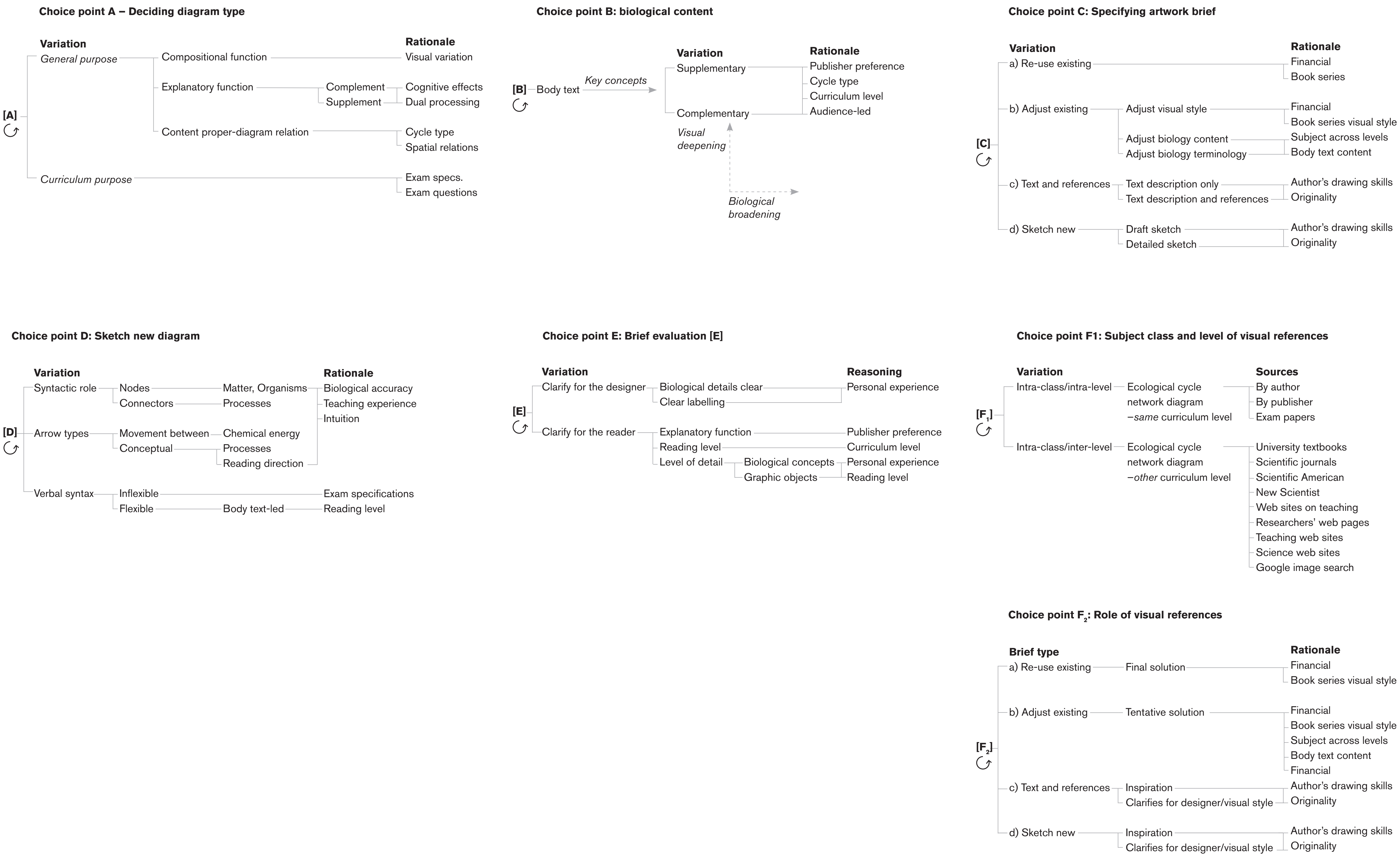


Figure 6.26: Variation in approaches and rationale at choice points in brief development

Overview of the tree diagrams presented in section 6.5.



Problem-solution co-evolution in brief development. Brief types a) and b).

Status of design decisions according to brief types; reflecting the implications of decision making at Choice point C on decision sequence
Status attended to is indicated in bold at each point.

Figure 6.27: Sequence of choice points for brief type a) re-use existing diagram
Overall problem represents the overall solution.

[A] Decide diagram type

Overall dimension	*Status of decision*
Diagram type	**Final solution**
Biological content	
Sub-dimension	
Nodes/Connectors	**Final sub-solutions**
Arrow types	
Pictorial object	
Visual attributes	
Typographic attributes	
Verbal syntax	

Figure 6.28: Sequence of choice points for brief type b) adjust existing diagram
Author may adjust biological content or terminology of existing references.

[A] Diagram type/author

Overall dimension	*Status of decision*
Diagram type	**Final solution**
Biological content	Transferred as sub-problem
Sub-dimension	
Nodes/Connectors	Transferred as sub-problems
Arrow types	
Pictorial object	
Visual attributes	Tentative sub-solutions*
Typographic attributes	Final sub-solutions
Verbal syntax	Transferred as sub-problems

[F] Visual references/author

Overall dimension	*Status of decision*
Diagram type	Final solution
Biological content	Transferred as sub-problem
Sub-dimension	
Nodes/Connectors	**Tentative sub-solutions**
Arrow types	
Pictorial object	**Tentative sub–solutions**
Visual attributes	Tentative sub-solutions*
Typographic attributes	Final sub-solutions
Verbal syntax	Transferred as sub-problem

[B] Biological content/author

Overall dimension	*Status of decision*
Diagram type	Final solution
Biological content	**Tentative solution**
Sub-dimension	
Nodes/Connectors	Tentative sub-solutions
Arrow types	
Pictorial object	
Visual attributes	Tentative sub-solutions*
Typographic attributes	Final sub-solutions
Verbal syntax	**Tentative sub-solution**

[E] Evaluate brief/editor

Overall dimension	*Status of decision*
Diagram type	**Final solution**
Biological content	
Sub-dimension	
Nodes/Connectors	**Final sub-solutions**
Arrow types	
Pictorial object	
Visual attributes	Tentative sub-solutions*
Typographic attributes	Final sub-solutions
Verbal syntax	**Final sub-solution**

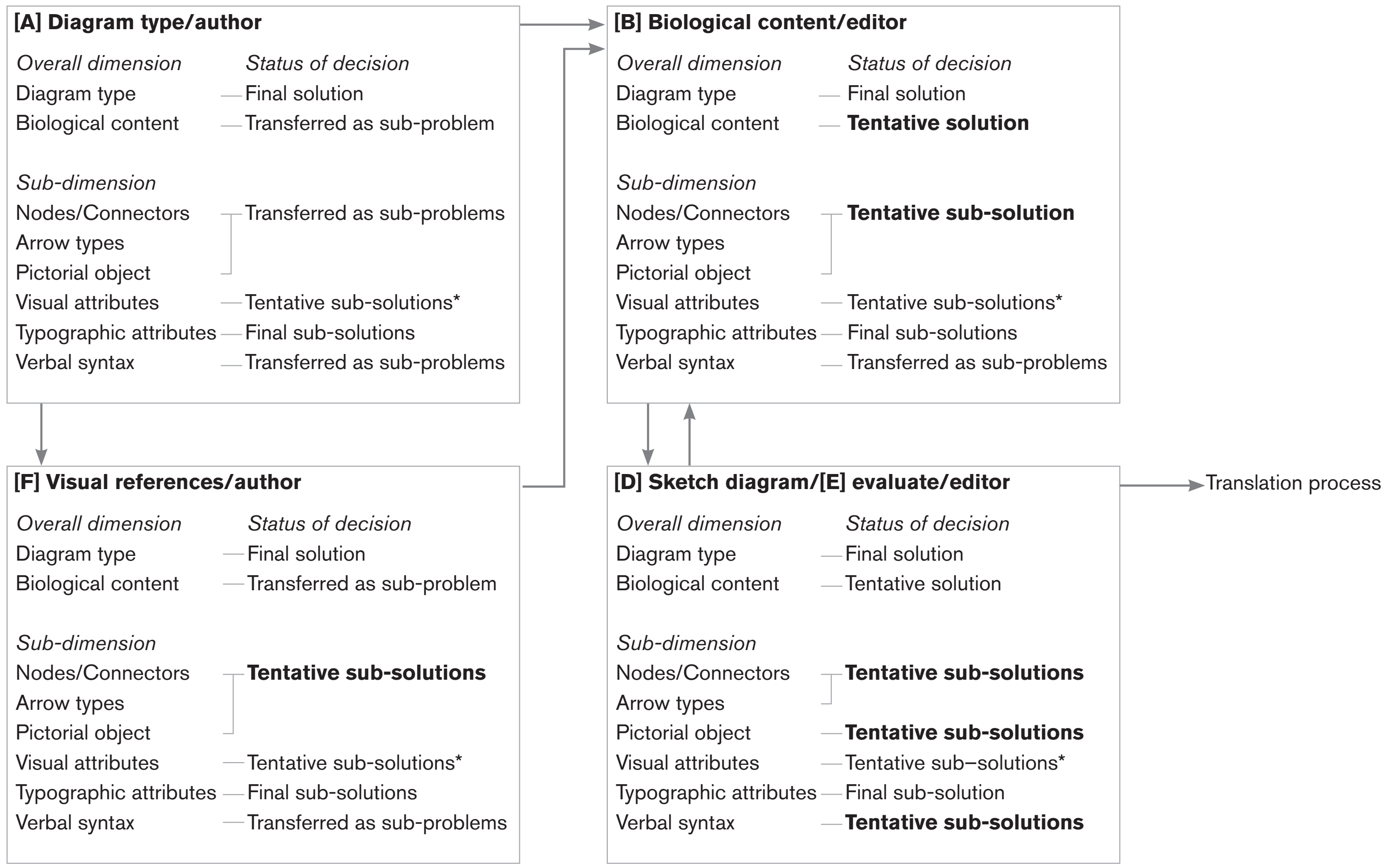
→ Translation process

*Visual attributes: colour and texture may be set by page layout, shape and size are tentative sub-solution.

Problem-solution co-evolution in brief development. Brief type c).

Status of design decisions according to brief types; reflecting the implications of decision making at Choice point C on decision sequence
Status attended to is indicated in bold at each point.

Figure 6.29: Sequence of choice points for brief type c) text and references
Author decides diagram type and may indicate biological content by visual references.
Editor decides biological content and sketches diagram, whilst evaluating.

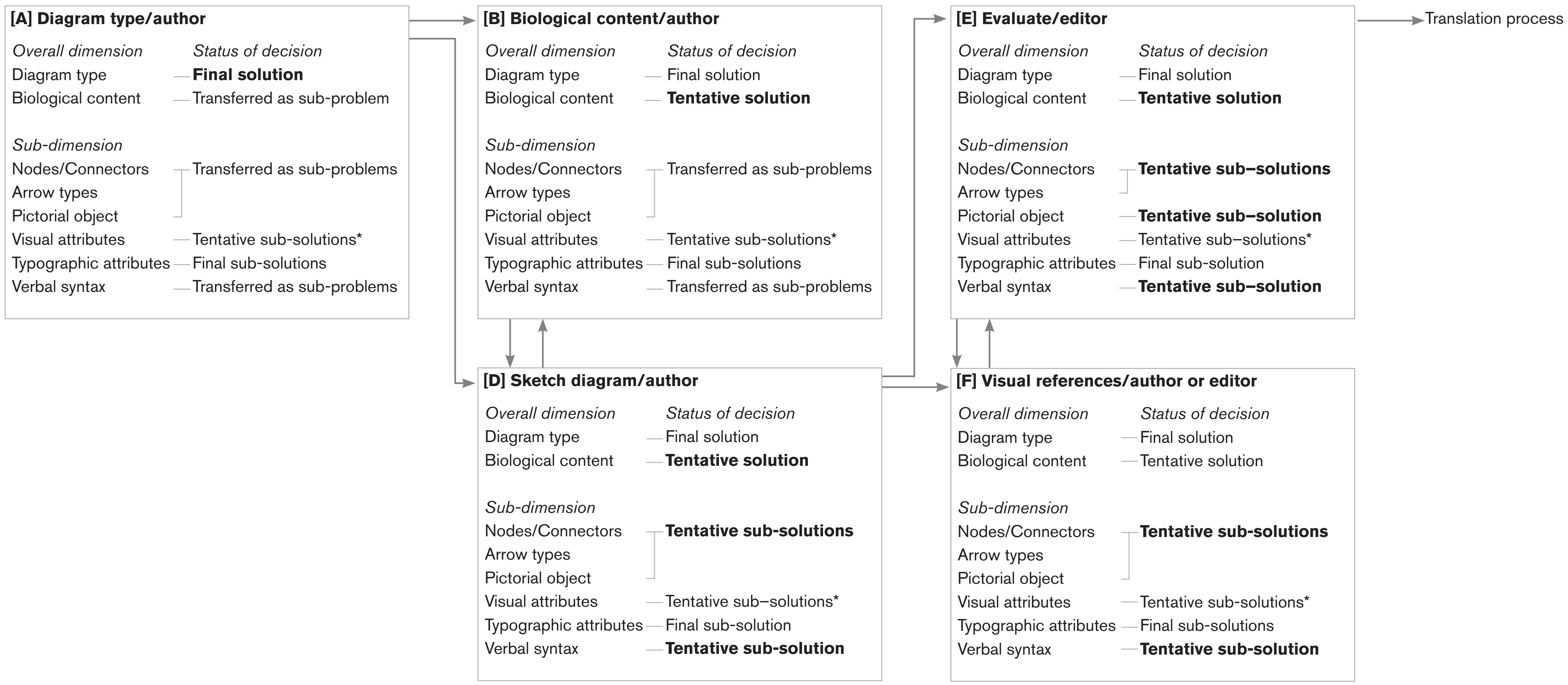


*Visual attributes: colour and texture may be set by page layout, shape and size are tentative sub-solution.

Problem-solution co-evolution in brief development. Brief type d).

Status of design decisions according to brief types; reflecting the implications of decision making at Choice point C on decision sequence
Status attended to is indicated in bold at each point.

Figure 6.30: Sequence of choice points for brief type d) sketch now diagram.
Author decides diagram type, biological content, sketches diagram, and may include
visual references as inspiration or clarification. Editor evaluates and may include visual references.



*Visual attributes: colour and texture may be set by page layout, shape and size are tentative sub-solution.

Problem-solution co-evolution in information transformation process. Brief types a) and b)

Status of design decisions according to brief types; reflecting the implications of decision making at Choice point C on decision sequence

Status attended to is indicated in bold at each point.

Figure 6.38: Sequence of choice points for brief type a) re-use existing diagram

Overall problem represents the overall solution.

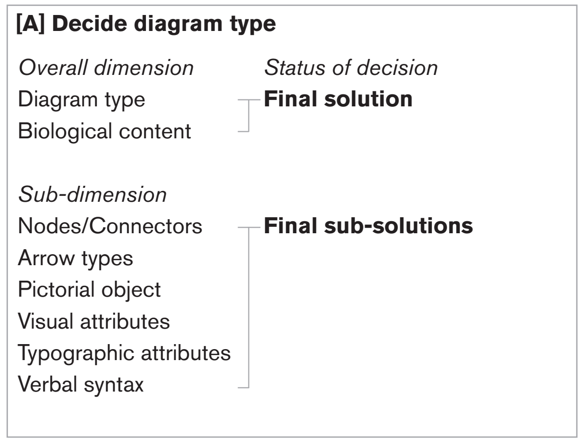
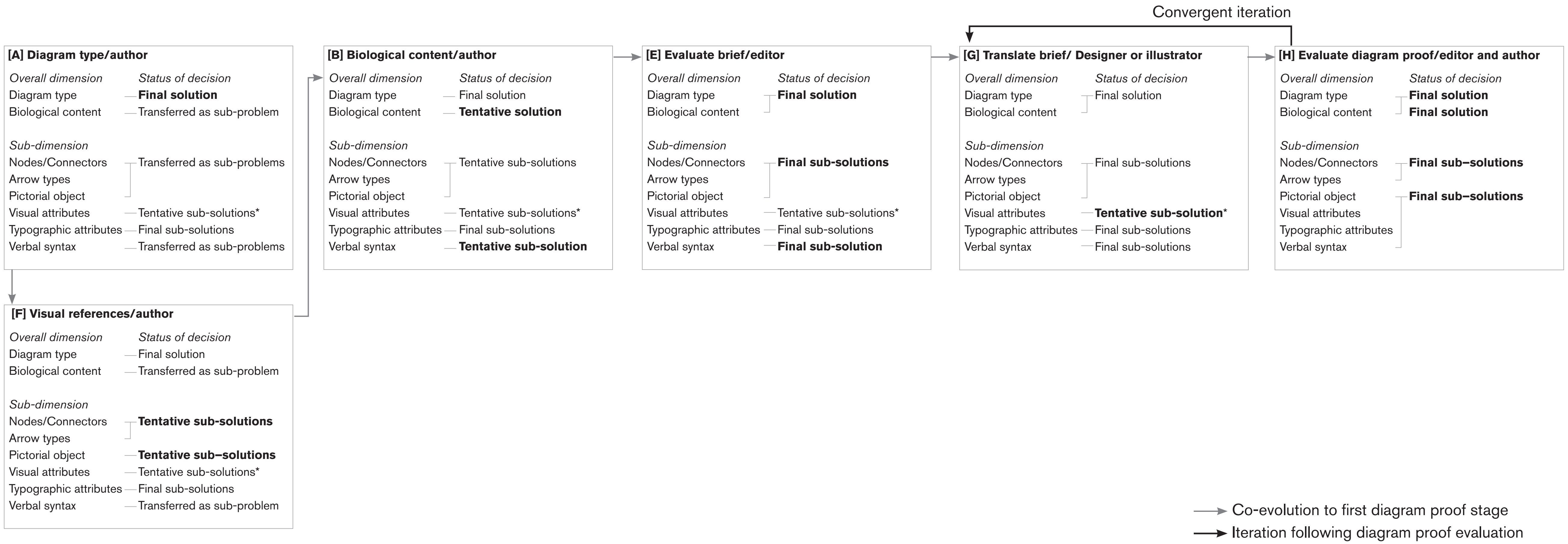


Figure 6.39: Sequence of choice points for brief type b) adjust existing diagram

Author may adjust biological content or terminology of existing references.

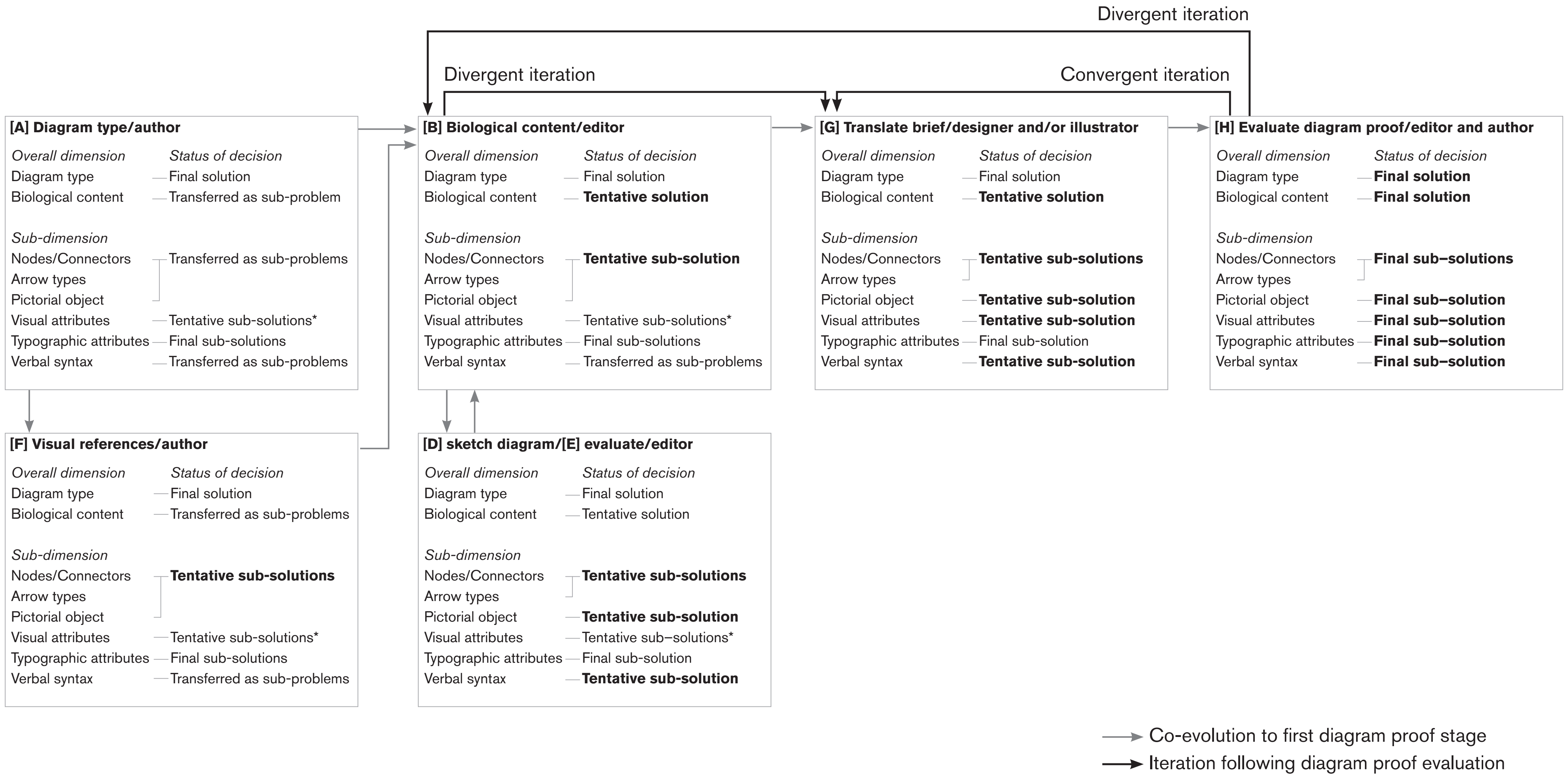


*Visual attributes: colour and texture may be set by page layout, shape and size are tentative sub-solution.

Problem-solution co-evolution in information transformation process. Brief type c).

Status of design decisions according to brief types; reflecting the implications of decision making at Choice point C on decision sequence
Changes in status are indicated in bold at each point.

Figure 6.40: Sequence of choice points for brief type *c*, text and references
Author decides diagram type and may indicate biological content by visual references.
Editor decides biological content and sketches diagram, whilst evaluating.
Designer/illustrator translate brief.
Editor and authors evaluate, resulting in divergent or convergent iterations.



*Visual attributes: colour and texture may be set by page layout, shape and size are tentative sub-solution.

Problem-solution co-evolution in information transformation process. Brief type d).

Status of design decisions according to brief types; reflecting the implications of decision making at Choice point C on decision sequence

Changes in status are indicated in bold at each point.

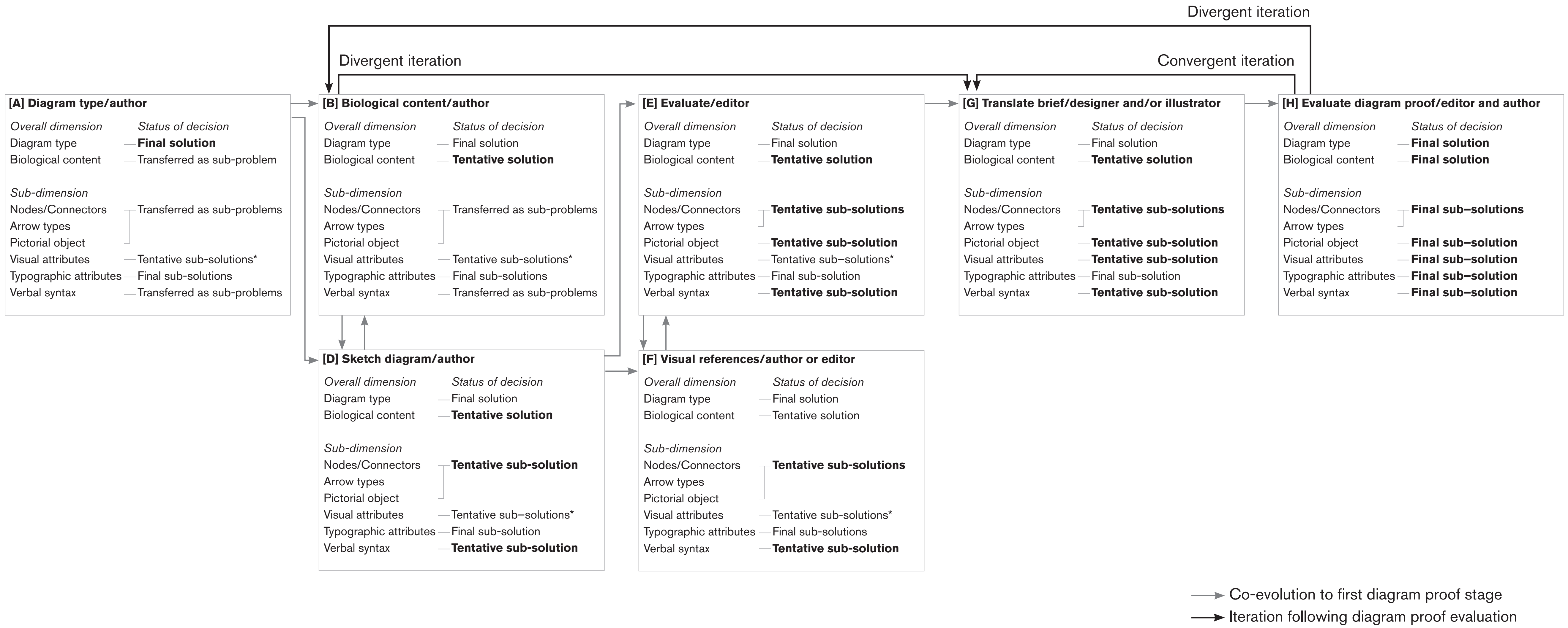
Figure 6.41: Sequence of choice points for brief type d) sketch now diagram

Author decides diagram type, biological content, sketches diagram and may include visual references as inspiration or clarification.

Editor evaluates and may include visual references.

Designer/illustrator translate brief.

Editor and authors evaluate, resulting in divergent or convergent iterations.



*Visual attributes: colour and texture may be set by page layout, shape and size are tentative sub-solution.

Table 7.3: Checklist for addressing individual ineffective graphic tactics

Ineffective graphic tactic		Content proper implication	Related coding values/graphic syntax aspect	Recommendations to observe
Coding variable 1 – basic syntactic role				
1	Implicit nodes: Branching arrow Section [4.4.1.1 / 5.2.2.1]	Indicates an implicit connected element. Ambiguity about nature of connected and connecting element.	Not applicable - analysed separate from explicit nodes.	Branching arrow may be avoided by using two arrows exiting the node.
2	Implicit nodes: Merging arrows Section [4.4.1.2 / 5.2.2.1]			Merging arrow may be avoided by using two arrows entering the node.
3	Implicit nodes: Arrow-arrow connection Section [4.4.1.3 / 5.2.2.1]			Arrow-arrow connection may be avoided by consistent node-arrow-node sequences.
4	Implicit nodes: Intersecting arrows Section [4.4.1.4 / 5.2.2.1]			Intersecting arrows may be avoided by re-organising individual node and connector sequences, and by reducing number of graphic objects in the diagram.
5	Imprecise nodes/arrow labels: Imprecise relative spatial positioning [Section 4.4.1.5 / 5.2.2.1]	Ambiguity about the nature and role of connected and connecting element.	Coding variable 2/Pictorial object labels Coding variable 5/typographic attributes: · Nondistinctive nodes and arrows	Imprecise relative spatial positioning may be avoided by re-organising individual node and connector sequences, and by reducing number of graphic objects in the diagram, or text in a label/node.
6	Explicit nodes: Unlabelled pictorial object [Section 4.4.1.6 / 5.2.2.2]	Polysemic connected object. Ambiguity about nature of connected element.	Coding variable 1/syntactic role: · Polysemy within nodes Coding variable 2/Pictorial object labels: · Polysemic pictorial objects	Labelling all pictorial objects increases monosemy.
7	Explicit connectors: Unlabelled arrow [Section 4.4.1.6 / 5.2.2.2]	Polysemic connected object. Ambiguity about nature of connecting element.	Coding variable 1/syntactic role: · Polysemy within connectors. Coding variable 3/arrow types: · Polysemic arrow types	Labelalling arrows increases monosemy.
8	Explicit nodes and connectors: Multiple information types – polysemic [Section 4.4.1.7 / 5.2.2.3]	Hinders positive redundancy when reading diagram. Ambiguity about the nature and roles of connected or connecting elements.	Coding variable 1/syntactic role: · Polysemy within nodes or connectors. Coding variable 2/Pictorial object labels: · Polysemic pictorial objects Coding variable 3/arrow types: · Polysemic arrow types Coding variable 6/Verbal syntax	It is recommended that nodes which include more than one information type are consistent in use of invariable and variable information types, eg 'process and agent', 'process and organisms'.
9	Categorising organisms in connector roles [Section 4.4.1.6 / 5.2.3.1]	Elements such as bacteria appear as circulating, rather than agents of transformation processes.	Coding variable 3/arrow types: · Arrow types	It is recommended that organisms are included in nodal roles, unless their process agent role is explicit.
10	Explicit connectors: Excluding matter from connector roles [Section 4.4.1.6 / 5.2.3.2]	Essential circulating elements are implicit; ambiguity about the nature of connecting elements.		It is recommended that the circulating element is made explicit.
11	Explicit connectors: Process in connector roles [Section 4.4.1.6 / 5.2.3.3]	May dislocate processes outside their related element. Creates ambiguity about the role of connecting elements.		Make the conceptual nature of process links explicit to explain the dislocation.

Ineffective graphic tactic		Content proper implication	Related coding values/graphic syntax aspect	Recommendations to observe
12	Exclusively unlabelled arrows [Section 4.4.1.6 / 5.2.3.4]	Ambiguity about the nature and role of connected element. May indicate movement of elements in source nodes.	Coding variable /syntactic role: · Polysemy across nodes Coding variable 6/Verbal syntax	It is recommended that all arrows are labelled to increase monosemy.
13	Polysemy within a syntactic role [Section 4.3.1.7 / 5.2.3.4]	Ambiguity about the nature and role of connected or connecting elements. Hinders positive redundancy when reading a diagram.	Coding variable /syntactic role: · Single information types Coding variable 2/Pictorial object labels: · Polysemic pictorial objects Coding variable 3/arrow types: · Polysemic arrow types Coding variable 4/Visual attributes Coding variable 5/Typographic attributes	Applying clear and consistent visually distinction to nodes or connectors which include different information types increases monosemy.
Coding variable 2 –pictorial object labels				
14	Text image relationship inconsistent [Section 4.4.2.1 / 5.3.2.1]	Ambiguity about the nature of connected elements. Hinders positive redundancy when reading a diagram.	Coding variable /syntactic role: · Single information types · Multiple information types	It is recommended that the text image relationships are consistent, for example, all pictorial objects represent process or organisms.
15	Polysemic pictorial objects [Section 4.4.2.1 / 5.3.3.1]	Ambiguity about the nature of connected elements.	Coding variable /syntactic role: · Single information types · Multiple information types · Polysemy across nodes Coding variable 4/Visual attributes Coding variable 5/Typographic attributes	If more than one information type is included within pictorial object labels, it is recommended to apply clear and consistent visual distinction.
Coding variable 3 – arrow types				
16	Polysemic arrow types [Section 4.4.3 / 5.4.2.1]	Ambiguity about the nature and role of connected or connecting elements. Hinders positive redundancy when reading a diagram.	Coding variable 1/syntactic role: · Single information types · Multiple information types · Polysemy across connectors Coding variable 4/Visual attributes Coding variable 5/Typographic attributes	When including more than one arrow type in a diagram, it is recommended that the different types are visually distinct, and labelled to indicated the type of connection, ie chemical transfer or transformation.
Coding variable 4 – visual attributes				
17	Nominal visual attributes: Inconsistent shape [Section 4.4.4.1 / 5.5.2.1]	Ambiguity about nature of grouped elements within nodes or arrows.	Coding variable 1/syntactic role: · Single information types · Multiple information types · Polysemy across nodes and connectors	Applying shape visual attribute with consistent information-attribute relations increases consistency. Alternatively exclude container shapes.
18	Nominal visual attributes: Inconsistent colour within syntactic role [Section 4.4.4.1 / 5.5.2.2]			Apply clear visual distinction to disassociated information types – within a syntactical role – and visual similarity to associated elements.
19	Nominal visual attributes: Inconsistent colour *between* syntactic roles [Section 4.3.4.1 / 5.2.4.2]	Ambiguity about nature and role of grouped elements between nodes or arrows.		Apply clear visual distinction to disassociated information types – across a syntactical role – and visual similarity to associated elements.
20	Ordinal visual attributes: Inconsistent texture [Section 4.4.4.2 / 5.5.2.3]	Ambiguity about nature and hierarchy of grouped elements within nodes or arrows.		Apply clear visual distinction to disassociated information types – within a syntactical role – and visual similarity to associated elements.
21	Quantitative visual attributes: Inconsistent size [Section 4.4.4.3 / 5.5.2.4]	Ambiguity about relative quantities represented, the hierarchy, and nature of grouped elements within nodes or arrows.		Apply size visual attribute with relative information-attribute consistency. Or, alternative exclude.

	Ineffective graphic tactic	Content proper implication	Related coding values/graphic syntax aspect	Recommendations to observe
Coding variable 5 – typographic attributes				
22	Nondistinctive nodes and arrow labels [Section 4.4.5.1 / 5.6.1.1]	Ambiguity about role of connected or connecting elements.	Coding variable 1/syntactic role: · Single information types · Multiple information types	Creating visual distinction between disassociated connected and connecting elements increases consistency.
Coding variable 6 – Verbal syntax				
24	Inconsistent verbal syntax in nodes [Section 4.3.6.1 / 5.2.6.1]	Hinders positive redundancy when reading diagram; ambiguity about nature and role of connected elements	Coding variable 1/syntactic role: · Single information types · Multiple information types	Including similar verbal syntax in all nodal text objects increases consistency.
25	Inconsistent verbal syntax in arrow labels [Section 4.3.6.1 / 5.2.6.1]	Hinders positive redundancy when reading diagram; ambiguity about nature and role of connecting elements		
26	*Nouns in arrow labels* [Section 4.3.6.1 / 5.2.6.1]	May result in reading a 'movement between' arrow type and chemical transformation instead of transfer.	Coding variable 1/syntactic role: · Single information types · Multiple information types Coding variable 3/arrow types: · Arrow types	Including similar verbal syntax in all arrow text objects increases consistency.
Verbal and graphic syntax interactions [appendix 6]				
26	Inconsistent linear verbal link within graphic objects [Appendix 6]	Verbal syntax may emphasise or verbally direct the visual routing. Indicating start and finishing points in content proper.	Coding variable 1/syntactic role: · Single information types · Multiple information types Coding variable 3/arrow types: · Arrow types Coding variable 5/Typographic attributes	Creating consistent linear linking and align visual and verbal start/end points increases consistency.
27	Inconsistent noun and verb phrases [Appendix 6]	Verbal syntax may emphasise or verbally direct the visual routing. A 'broken' verbal link hinders positive redundancy when interpreting the text objects and verbal omissions may increase ambiguity about nature and role of elements		Ensuring logical linking sequences through consistent noun and verb phrases increases consistency.
28	Inconsistent passive and active voice [Appendix 6]	Indicates which of linked text objects serve as grammatical objects and subjects. Active voice indicates the element in first node as the grammatical agent, passive voice indicates element in arrow as grammatical agent. May increase ambiguity about nature and role of elements		Ensure logical linking sequences through consistent use of active and passive voice within verb phrases.
29	Inconsistent prepositions [Appendix 6]	Indicates spatial and temporal relations between content proper information categories within single text object and in turn the connected / connecting elements. May increase ambiguity about nature and role of elements		Consistent use of prepositions in relation to implicit chemical transfers or transformations may ensure logical linking sequences.