International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

The effects of explicit visual cues in reading biological diagrams

Yun-Ping Ge, Len Unsworth & Kuo-Hua Wang

To cite this article: Yun-Ping Ge, Len Unsworth & Kuo-Hua Wang (2017): The effects of explicit visual cues in reading biological diagrams, International Journal of Science Education, DOI: 10.1080/09500693.2017.1297549

To link to this article: http://dx.doi.org/10.1080/09500693.2017.1297549

Published online: 24 Mar 2017.

Submit your article to this journal

Article views: 2

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
http://www.tandfonline.com/action/journalInformation?journalCode=tsed20

Download by: [University of Colorado at Boulder Libraries] **Date:** 26 March 2017, At: 05:41

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2017
http://dx.doi.org/10.1080/09500693.2017.1297549

Routledge
Taylor & Francis Group

Check for updates

The effects of explicit visual cues in reading biological diagrams

Yun-Ping Ge[a], Len Unsworth[b] and Kuo-Hua Wang[a]

[a]Graduate Institute of Science Education, National Changhua University of Education, Changhua, Taiwan; [b]Learning Sciences Institute Australia, Australian Catholic University, Sydney, NSW, Australia

ABSTRACT

Drawing on cognitive theories, this study intends to investigate the effects of explicit visual cues which have been proposed as a critical factor in facilitating understanding of biological images. Three diagrams from Taiwanese textbooks with implicit visual cues, involving the concepts of biological classification systems, fish taxonomy, and energy pyramid, were selected as the reading materials for the control group and reformatted in tree structure or with additional arrows as the diagrams for the treatment group. A quasi-experiment with an online reading test was conducted to examine the effect of the different image conditions on reading comprehension of the two groups. In total, 192 Taiwanese participants from year 7 were assigned randomly into either control group or treatment group according to the pre-test of relevant prior knowledge. The results indicated that not all explicit visual cues were significantly efficient. Only the explicit tree-structured diagrams cued significantly the key concepts of qualitative class-inclusion, parallel relations, and fish taxonomy. Meanwhile the effect of indexical arrows was not significant. The inconsistent effect of tree structure and arrows might be related to the extent of image reformation in which the tree-structured diagrams had undergone radical change of knowledge representation; meanwhile, the arrows had not changed the diagram structure of energy pyramid. The factor of prior knowledge was essential in considering the influence of image design as the effect of diagrams was very different for low and high prior knowledge students. Implications are drawn for the importance of visual design in textbooks.

ARTICLE HISTORY
Received 1 September 2016
Accepted 16 February 2017

KEYWORDS
Visual media; multiple representations; biology education; reading comprehension

Introduction

Diagrams play a crucial role in science learning. Biology textbooks use variant forms of diagrams to convey scientific information. However, not all textbook diagrams are beneficial to learning. Only those in efficient designs can facilitate knowledge construction (Larkin & Simon, 1987; Schnotz & Bannert, 2003; Seufert, 2003). Ill-designed diagrams might cause misunderstandings or misconceptions (Eilam, 2013).

CONTACT Yun-Ping Ge yunpingge@yahoo.com.tw Graduate Institute of Science Education, National Changhua University of Education, No. 835-6, Fushun Rd, Xitun Dist. Changhua 407, Taiwan

© 2017 Informa UK Limited, trading as Taylor & Francis Group

Most of the problems concerning visual design result from inaccuracy (Pinto & Ametller, 2002; Stylianidou & Ogborn, 2002), too many unnecessary details (Lee, 2010a; Mayer, 2001), confusing components (Blystone & Dettling, 1990), or inappropriate formats (Canham & Hegarty, 2010; Catley, Novick, & Shade, 2010; Shah, Hegarty, & Mayer, 1999). A recent science textbook survey indicates that the designs of taxonomic visual representation are diversified: only a few have salient tree structures to represent the intended hierarchical relationships, whereas the majority of visual representations adopt a combination of photographs with implicit visual structures (Ge, Unsworth, Wang, & Chang, in press-b). Research on improving visual designs has contributed considerable understanding about depicting the concepts of the classification system and evolution (Catley, Phillips, & Novick, 2013; Novick & Catley, 2007). However, most of the studies focus on university level rather than the novice learners in junior high school.

While theorists have proposed effective visual designs (Fleming, 1987; Kosslyn, 2006), only a few of them have been empirically validated (Canham & Hegarty, 2010; Shah et al., 1999). It is argued that explicit visual cues, such as arrows and tree structures, are able to highlight the key concepts in images so that the recognition of target ideas are privileged (Larkin & Simon, 1987; Novick & Catley, 2007). However, an evaluation of image design empirically is necessary because the actual effectiveness of images is not always in line with people's intuitions (Hegarty, 2011). Also the viewer's prior knowledge has been identified as a crucial factor in reading comprehension (Cook, Wiebe, & Carter, 2008). It has been proposed that the readers either with insufficient or with high level of prior knowledge are less likely to be influenced by the visual representation (Cook et al., 2008; Seufert, 2003). Hence, it would appear that it is the readers with a medium level of prior knowledge who can benefit most from the visual aids. Our investigation concerns the extent to which explicit visual cues enhance comprehension and under what conditions of prior knowledge.

Research question

The intention of this study is twofold: first, to reformat informationally equivalent diagrams with explicit visual cues to function as counterparts of some textbook images which are assumed to be less effective in visual design; second, to empirically examine whether the hypothesis that reformatted diagrams facilitate better comprehension in the same verbal context than the original textbook diagrams. Since the students are novice learners of the materials, it is important that the reformatted diagrams are informationally accessible to understanding. Therefore, the prior knowledge is a priori concern in the diagram reformation and empirical test.

Visual design in science learning

What counts as a better visual design has been a focus of many studies seeking to improve viewers' comprehension (Canham & Hegarty, 2010; Hegarty, 2011; Shah et al., 1999). The actual effectiveness of visual representations is mostly determined by perceptual and cognitive processes. There are three major cognitive processes in meaning-making (de Koning, Tabbers, Rikers, & Paas, 2009; Mayer, 1992): Selecting relevant information from a diagram, organising information into coherent representation, and integrating relations between and within elements. Therefore, the effect of image design depends strongly on whether the key features in a display are explicitly represented (Larkin & Simon, 1987). Explicit features can direct attention to select the critical attributes and focus on the most relevant information (Beck, 1984). For example, many young readers of the following diagram (shown as Figure 1), which intended to name the grey wolf in the classification system, were not able to select the key features from the diagram and then their interpretation remained on the surface features of the colourful ladder-like boxes, juxtaposed animals, or big vertical blue arrow (Ge, Unsworth, Wang, & Chang, in press-a). The failure of selecting key features in the initial stage of perception also led to the inability in organising the information to identify the grey wolf in different hierarchical levels.

According to cognitive theory, visual perception is extremely selective so that readers can focus attention only on a limited number of elements in a diagram at once (de Koning et al., 2009). The difficulty students experienced with Figure 1 is highly related to the distraction caused by many salient features (Kozma, 2003).

When the same animals in Figure 1 are re-presented in another way to highlight the hierarchical theme rather than the animals or other irrelevant information (Fabrikant, Rebich-Hespanha, & Hegarty, 2010), such as Figure 2, readers were much more likely to spontaneously identify the main idea as a kind of classification (Ge et al., in press-a). In Figure 2, the representation has been reformatted in three ways according to the

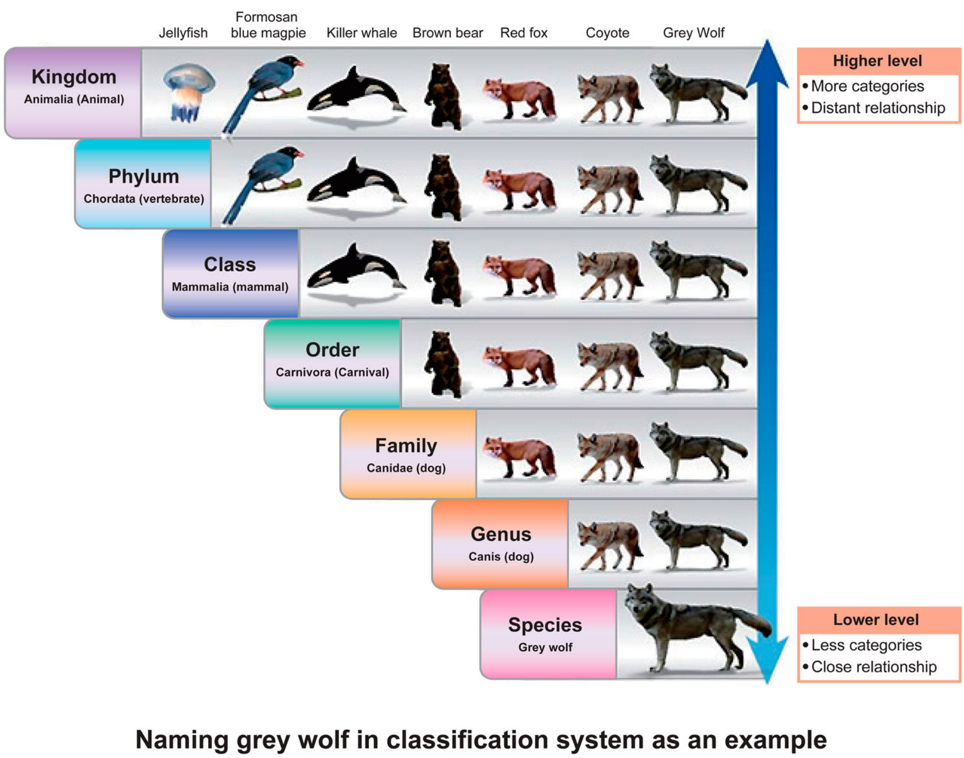


Figure 1. A textbook diagram representing the biological classification system by naming grey wolf as an example (translated from Chen, Fang, Yao, Hsu, & Lee, 2010, p. 98, Figure 4–3).

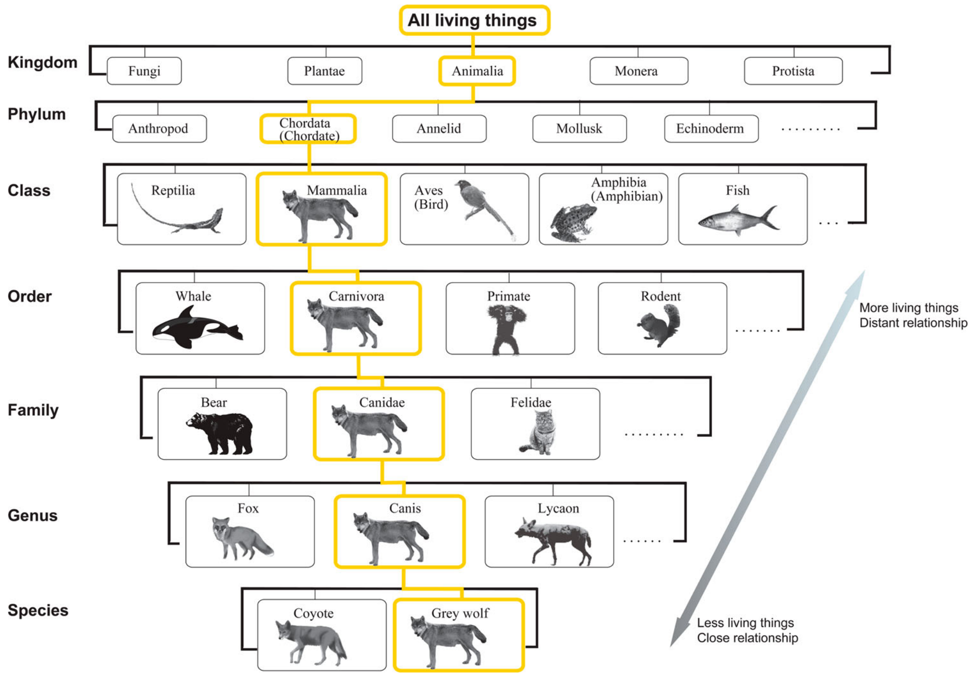


Figure 2. A reformatted diagram referring to Figure 1.

three cognitive processes of visual comprehension. First, to replace the diagram pattern from the colourful boxes into a yellow tree structure so that the structure can stand out against surrounding grey elements because of luminance contrast (Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001; Schnotz & Lowe, 2003). According to the guidelines of cueing perceptual processes, increasing the luminance contrast is able to draw viewers' attention to essential elements (de Koning et al., 2009). Furthermore, tree structure has been verified as a powerful tool in representing hierarchical relations in pedigree and cladogram and in externalising the internal knowledge structure (Ifenthaler, 2010; Novick, 2001; Novick & Catley, 2007).

Second, to reduce the colours of animals and less relevant information into grey also minimises the cognitive load and increases the ease of recognition. According to cognitive load theory, learners' cognitive resources are very limited so that the perception will be overwhelmed by too much information (Chandler & Sweller, 1991; Sweller, van Merrienboer, & Paas, 1998). Third, drawing the related entities closely, such as the animals in the same classification levels, is able to facilitate information selection and subsequent processes to make meaning (Hegarty, 2011).

In terms of the efficiency of explicit visual cues, some studies focused on the diagram structure (Canham & Hegarty, 2010; Lee, 2010b; Novick & Catley, 2007; Schnotz & Bannert, 2003), whereas the others focused more on the indexical visual elements, such as arrows (Heiser & Tversky, 2006; Jennings & Dwyer, 1985; Pinto & Ametller, 2002). Like the x–y axis in a graph, tree structure is the skeleton of a diagram to encode the fundamental taxonomic concept of the domain through node-link assemblies in the cladogram representing evolutionary and classification relationships (Novick & Catley, 2007).

In a tree-structured diagram, a node represents a taxon and vertical interconnecting lines represent the inclusive relation between upper level and subordinate level in a given taxonomy (Körner, 2005; Novick & Catley, 2007). For example, in Figure 2, family Canidae qualitatively includes the genus Fox, Canis, Lycaon, and others. Quantitatively, the relative size of the family Canidae is bigger than the genus Fox. It is argued that the inclusive relation is not easy to perceive in learning the hierarchical concepts, especially when inference questions require transitivity of the understanding (Deneault & Ricard, 2005). For example, in Figure 1, the understanding that each row is subsumed by the row above must be inferred so that an animal classified as genus Canis is also a member of the family Canidae. If the transitivity fails, then comprehension will not be possible. However, the inference in Figure 2 will be easier due to the direct pattern perception with the aids of the interconnecting lines and the nodes. Shah et al. (1999) argued that diagram comprehension involves two kinds of processes: first, direct pattern perception in which viewers can directly associate the diagram format with some ideas; second, more complex and indirect pattern perception in which the visual information has to be mentally transformed in order to access the meaning. The first kind of comprehension is relatively simple but the second kind is difficult and error-prone.

In regard to indexical visual cues, the arrow has been recognised as an efficient element which could not only draw attention, but also be able to convey sequential and dynamic relations (Beck, 1984; Heiser & Tversky, 2006). The label of arrowhead denotes asymmetric relations which suggest other possible meanings, such as motion, causal, or temporal relations (Kress & van Leeuwen, 2006; Tversky, 2011). Many studies suggested that the adoption of the arrow could visualise the direction of the invisible biotic and abiotic processes embedded in learning cyclic process, such as the carbon cycle, which has been identified as difficult for many students (Eilam, 2013; Hmelo-Silver & Azevedo, 2006). Readers could have produced more descriptions about the sequence of actions, dynamic operations, and causal relations when they read the images with arrows (Heiser & Tversky, 2006). However, not all the studies supported the positive effects of arrows. The variety of possible meanings conveyed by arrows has been a source of difficulties for some students (Pinto & Ametller, 2002; Tversky, Heiser, Lozano, MacKenzie, & Morrison, 2007). Moreover, it is suggested that inappropriate use of arrows in a cycle representing the relationships between photosynthesis and respiration could have misled viewers to identify that the substances are cycled in a plant cell (Stern & Roseman, 2004).

The findings outlined above indicate both the promise of a cognitive science approach and the challenges that lie ahead in building up the approach to the comprehension of visual designs.

Reading comprehension in multiple representations

In science textbooks today, presentations that involve visual and verbal information are widely used as instructional materials (Cook, 2006; Unsworth, 2001). The meaning-making in reading multiple representations requires the integration of text-based perception and image-based perception into one mental model through the process of structure mapping (Gentner & Markmann, 1997; Seufert, 2003). Multiple representations can complement each other in alternative modes with regard to the content and representational efficiency, constrain possible interpretation, and construct deeper understanding (Ainsworth, 1999). With the inherent property of representing specific spatial relationships, visual display provides readers with an alternative way of representing the abstract and complicated scientific concepts which are difficult to describe with verbal text (Ainsworth, 1999; Cook, 2006; Kress & van Leeuwen, 2006). It is believed that knowledge construction will be fostered and information retention will be reinforced with the visual display (Peeck, 1993). However, if visual display fails to associate with the verbal representation, it would be difficult for readers to form coherent meaning between verbal and visual representations (Ainsworth, 2006; Seufert, 2003). For example, Figure 1, by representing kingdom Animalia only, misses the other four kingdoms in the same hierarchical level which are also not mentioned in the verbal text. The missing depiction of this parallel relation in the classification system forms a gap which is the greatest potential reason why many readers could not tell the existence of other classificational units (Ge et al., in press-a).

The influence of prior knowledge in reading comprehension

Individual prior knowledge is a determinant factor in reading comprehension (Cook et al., 2008; Seufert, 2003). Based on textual information, readers with high levels of prior knowledge, more like experts, can access a large amount of topic-relevant information with little effort. In contrast, the learners with little prior knowledge tend to pay attention to surface features in diagrams (diSessa, 2004; Kozma, 2003; Patrick, Carter, & Wiebe, 2005). In reading diagrams with verbal text, low prior knowledge learners' interpretations remain at the literal meaning due to their limited ability to coordinate the features between different representations (Cook et al., 2008; Seufert, 2003). Therefore, the role of diagrams was very different for low and high prior knowledge students.

Methodology

A quasi-experiment was conducted using a large-scale online reading comprehension test which was developed to record individual-specific information, including response to the questions, reading time, and frequency of re-reading the passages (He & Tymms, 2005). With the aid of the computers, the test can be manipulated to be presented either in the condition of answering questions with passage availability or in the condition of answering the questions without the passage availability. If readers are allowed to re-read the passage for unlimited time while answering the questions, the impact of short-term memory constraints could be reduced (Andreassen & Brten, 2010). However, in the condition of responding without passage availability, recall as well as application is necessarily assessed.

Reading materials

The reading materials consist of three sets of independent texts and associated images. All the verbal texts for all the participants remain the same but the associated images are manipulated. For the control group, the first two diagrams are those from Taiwanese textbooks without explicit visual cues (shown as Figures 3 and 5). The corresponding diagram for the treatment group was reformatted according to the guidelines of effective visual design with verbal text (shown as Figures 4 and 6).

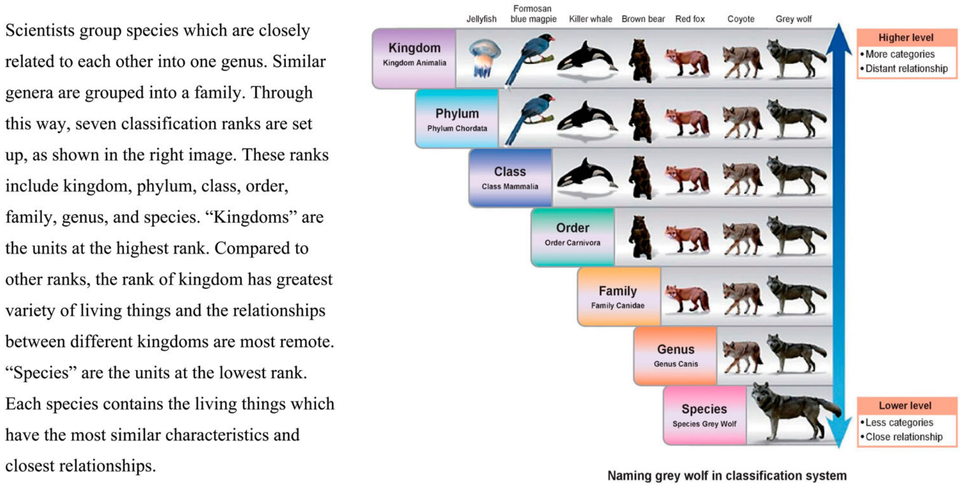


Figure 3. The reading material of classification system in Set 1 for the control group (translated from Chen et al., 2010, p. 98, Figure 4–3).

The topic of Set 1 is related to classification system and Set 2 deals with fish taxonomy. The control image in Set 2 implicitly represents the taxonomy of bony fish and cartilaginous fish by spatial arrangement (shown as Figure 5). In order to explicitly represent the taxonomic relations, a tree structure labelled with taxonomic terms was incorporated with the photo image of fish (shown as Figure 6). The original setting was deleted, minimising the visual interference.

In contrast with the explicit visual cue provided by the replacement tree structure in Set 1 and Set 2, the diagram in Set 3, as originally depicted in the textbook, remains the same pyramid structure but adds the additional indexical arrows to explicitly represent the source of energy in the ecosystem (yellow arrow labelled with sunlight), the direction of

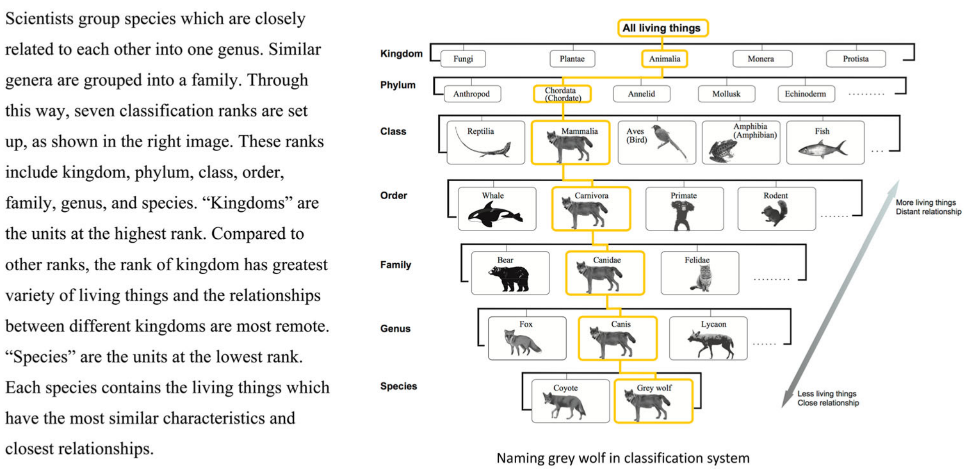


Figure 4. The reading material of classification system in Set 1 for the treatment group.

Fish

Fish live in water and breathe with gills. According to the quality of their skeletons, fish can be divided into cartilaginous fish and bony fish. The primary characteristic of cartilaginous fish is that their skeleton is composed predominantly of cartilage. Cartilaginous fish have gill slits. The commonly seen cartilaginous fish include sharks and stingrays. The vast majority of fish belong to the category of bony fish. The primary characteristic of bony fish is that they have a hard bony skeleton. Bony fish have an air bladder and operculum. Inside the operculum, there are gills. Bony fish have great varieties. For example, sea horses and clownfish are both bony fish.

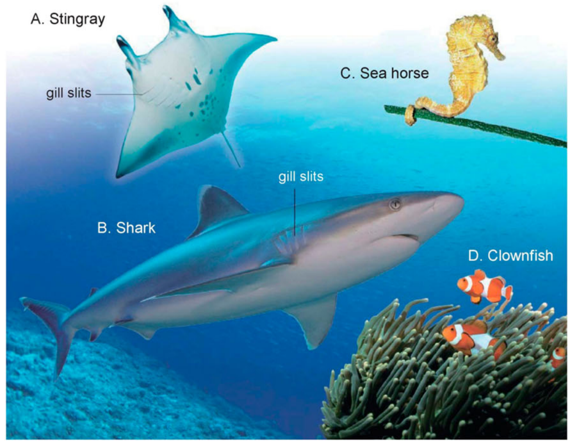


Figure 5. The reading material of fish taxonomy in Set 2 for the control group (translated from Lin, Lee, Huang, Chang, & Tsai, 2010, p. 104, Figure 4–35).

energy transference in the food chain (red arrows with different width indicating less remaining energy), and the heat loss in orange arrows (shown as Figure 8). In order to reduce the irrelevant visual details, the realistic photos of living things in the food chain have been replaced by drawings. Meanwhile, the pyramid with no arrows was assigned as a control diagram (shown as Figure 7).

Fish

Fish live in water and breathe with gills. According to the quality of their skeletons, fish can be divided into cartilaginous fish and bony fish. The primary characteristic of cartilaginous fish is that their skeleton is composed predominantly of cartilage. Cartilaginous fish have gill slits. The commonly seen cartilaginous fish include sharks and stingrays. The vast majority of fish belong to the category of bony fish. The primary characteristic of bony fish is that they have a hard bony skeleton. Bony fish have an air bladder and operculum. Inside the operculum, there are gills. Bony fish have great varieties. For example, sea horses and clownfish are both bony fish.

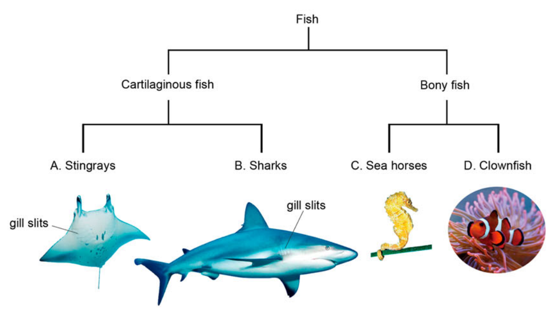
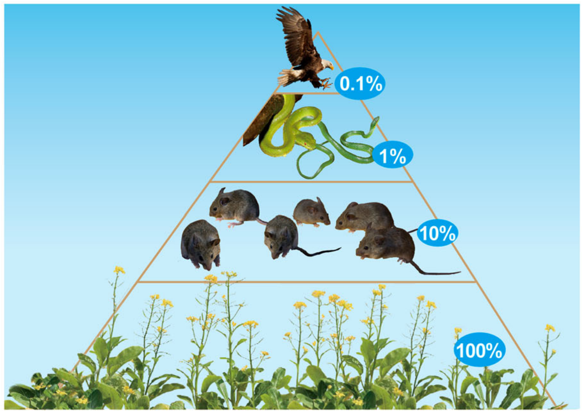


Figure 6. The reading material of fish taxonomy in Set 2 for the treatment group.

Energy pyramids

The energy in consumers' food is transferred along the food chain. In the process of energy transfer, most of the energy from producers is lost and becomes heat. Only about 10% of the energy is transferred from producers to consumers. When energy is transferred to the fourth or fifth level of consumers, only a small amount is left. Food chains are therefore usually not long.

In an ecosystem, the amount of energy produced from primary producers to support primary consumers must be the greatest in a food chain. As energy is lost progressively along the food chain, the amount of energy in the consumers at different levels is progressively reduced. This means that the consumers at the top level have the least amount of energy. The order of different amount of energy at different levels in a food chain can be represented through a diagram with the shape of a pyramid (wide at the bottom and narrow at the top). This is called an energy pyramid.



An energy pyramid

Figure 7. The reading material of energy pyramid in Set 3 for the control group (revised from Chen, Fang, Yao, Hsu, & Lee, 2013, pp. 148–149).

Participants

Two hundred and six year 7 students were recruited from two urban junior high schools in middle Taiwan as the participants. All the participants had not received the relevant lessons before the study. On the basis of a pre-test result, the participants were randomly assigned to either control group or treatment group. Initial analysis of pre-test means indicates no significant differences among the groups. Deleting some participants absent in the post-test, valid data remained for 192 participants and these were further differentiated into three levels of prior knowledge (low, medium, and high), according to the pre-test cut-offs from the lowest and highest 27th percentile.

Online reading comprehension assessment

The format of multiple-choice questions has been applied to assess the visual-based comprehension as well as the coherent information covered by the multiple representations. Based on the findings of interview data (Ge et al., in press-a), the multiple choice questions adopted the misunderstandings generated in reading these diagrams as distractors. In order to evaluate the extent of specific comprehension, two short-answer questions were employed in addition to those in the multiple-choice format. The responses were scored by rubrics and tested for inter-rater reliability.

The assessment consists of a pre-test and a post-test, each with a duration of 45 minutes. Both pre-test and post-test consist of the same 46 questions. Only the post-test has the accompanying passages. All the questions are classified according to two-way specifications: one way is subordinated to the key concepts represented by the passages; the other way is subordinated to the cognitive level of comprehension which is based on revised Bloom's taxonomy: memory, understanding, and application

(Krathwohl, 2002). Many key concepts are embedded in the three sets of reading materials. With respect to the classification system in Set 1, there are four key concepts: (1) qualitative class-inclusion, which means the animal in a subordinated class is always included in the relevant superordinate class; (2) quantitative class-inclusion, which means the number of animals in a subordiated class is always included in the relevant superordinate class; (3) parallel relations, which indicates the existence of other classificational units at the same hierarchical level; and (4) kinship relations, which indicate whether two animals share the most recent common ancestor in evolution.

In contrast, there is only one key concept represented in Set 2: fish taxonomy and another two in Set 3: structural information and functional information (Heiser & Tversky, 2006). The structural information consists of the static information describing separate parts of the food chain and ecosystem. In contrast, the functional information consists of the sequential relationship between the predators and preys, dynamic interaction between the food chain and the ecosystem, and their causal–result relationships.

Data analysis

Each score on the multiple-choice questions is one point, whereas the short-answer questions are graded according to the rubrics (shown as Appendix). For multiple-choice questions, the Cronbach's alpha is .89. The inter-rater reliability for short-answer questions is .82.

Results and discussion

Two major aspects of reading comprehension constitute this section: the influence of visual design and the impact of prior knowledge.

The influence of visual design

The hypothesis was tested with visual design as an independent variable. According to the statistical test of one-way ANOVA with prior knowledge as a covariant, the result is shown as in Table 1.

Based on Table 1, both the treatment visual designs in both Set 1 and Set 2 with explicit tree structure have a significant difference in contrast with the corresponding implicit structural design. In contrast, there is no significant difference in Set 3 between the indexical arrow cue and no cue related to the concept of energy pyramid.

The key concepts favoured by the treatment design

In addition to the result which confirmed the effect of diagrams with explicit tree structure, a further statistical test was conducted on the key concepts involved in the multiple

Table 1. The result of ANCOVA in three sets of the reading tests.

Set	Control group ($n = 94$) M (SD)	Treatment group ($n = 98$) M (SD)	F	Effect size
1. Classification system	14.93 (5. 90)	17.02 (6.77)	7.87**	.33
2. Fish taxonomy	6.46 (2.29)	7.33 (1.89)	10.21**	.41
3. Energy pyramid	9.44 (3.90)	10.29 (3.89)	2.24	.22

**$p < .01$.

representational passages (shown as Table 2). The result indicated that most of the key concepts which scored significantly higher were those that could be understood directly from the diagram with less need of inference. For example, the key concept of qualitative class-inclusion and parallel relationship in Set 1 were both favoured by the tree-structured design. Also the fish taxonomy was significant. However, functional information cued by indexical arrows did not align with the assumption that arrows could facilitate more functional information in systemic diagrams. This suggests that the expected efficiency of explicit visual cues is not valid in all conditions.

In order to verify the effect of inferential perception from Table 2, an examination of the participants' responses to the questions was developed. The following Question 11 is an example intended to investigate the key concept of qualitative class-inclusion. According to Figures 3 and 4, the verbal representation in Set 1 did not offer relevant information for the participants. Then the visual representation became the only resource to solve the problem:

11. 【 】 Which of the following statements about the relationships between Kingdom Animalia (animal) and Phylum Chordata (chordate) is correct?

A. Without jellyfish, then Kingdom Animalia becomes part of Phylum Chordata (chordate)

B. Kingdom Animalia (animal) includes Phylum Chordata (chordate) and Phyla in other titles

C. The animals that belong to Kingdom Animalia (animal) must also belong to PhylumChordata (chordate)

D. 'Kingdom' is the acronym of Kingdom Animalia (animal)

From Table 3, it can be seen that the number selecting the right answer B increased dramatically from 49 to 69 in the treatment group while it dropped in the control group because 34 participants were distracted by the wrong choice A. The selection of choice B required the participants to decode the visual chunk which refers to the part of the diagram representing the inclusive relation that Kingdom Animalia included

Table 2. The result of one-way ANCOVA of the key concepts in three sets of multiple representational passages.

	Set 1			Set 2		Set 3	
	Qualitative class-inclusion	Parallel relationship	Kinship relations	Quantitative class-inclusion	Fish taxonomy	Functional information	Structural information
Inferential perception	Direct	Direct	Indirect	Indirect	Direct	Direct	Direct
Treatment group Mean(SD)	5.35 (3.88)	4.66 (1.50)	3.83 (1.67)	3.18 (1.64)	6.94 (1.90)	6.07 (2.16)	2.85 (1.33)
Inferential perception	Indirect	Indirect	Indirect	Direct	Indirect	Indirect	Direct
Control group Mean(SD)	3.96 (3.37)	4.07 (1.26)	3.68 (1.57)	3.21 (1.29)	6.05 (2.36)	5.57 (2.06)	3.03 (1.39)
F	7.08**	10.22**	.29	.13	9.77**	.26	1.36
Effect size	.36	.43	.09	−.02	.42	.24	.13

**$p < .01$.

Table 3. The change of response in answering question #11.

	Control group		Treatment group	
Choice	Pre-test	Post-test	Pre-test	Post-test
A	6	34	10	4
B*	53	39	49	69
C	4	2	9	9
D	31	19	30	16

Phylum Chordata and other phyla. Figure 1 did represent the inclusive relation but in a way which required a referential transformation. Participants had to perceive that the box of animals connected to Phylum Chordata were the same as those in the wider box above. They also needed to understand that Phylum Chordata could be a subset of Kingdom Animalia because the number of animals in Phylum Chordata was less and the position of this box was underneath. In contrast, the node-link tree has been a conventional tool which powerfully triggers the inclusive relation embedded in the hierarchical structure. As a distractor, the choice A reflected the possible misunderstanding identified in a previous interview study (Ge et al., in press-a).

In addition to the qualitative class-inclusion, parallel relationships in the same hierarchical level were strongly supported by the tree-structured diagram. The following Question 2 is an example:

2. 【　　　】 According to modern biologists, how many kingdoms are there in the biological classification system?

   A. one

   B. two

   C. three

   D. five

Due to the absence of this verbal representation from the text, the selection of the correct choice D also depended on the visual perception. The response, shown by Table 4, reveals that the correct answers in the treatment group increase much more than the control group in the post-test. In Figure 2, the juxtaposition of five boxes aligned with 'Kingdom' appears to be the explicit indicator for the treatment group. In contrast, no visual clue in Figure 1 suggests five kingdoms in the system. The kingdom Animalia is the only one represented so that 34 novice learners were misled.

The detailed examination of responses reflected some other misunderstandings derived from the control diagrams. For example, 12 participants from the control group thought

Table 4. The change of response in answering question #2.

	Control group		Treatment group	
Choice	Pre-test	Post-test	Pre-test	Post-test
A	17	34	12	6
B	21	7	16	2
C	44	14	51	3
D*	12	39	19	87

Table 5. The change of response in answering question #18.

	Control group		Treatment group	
Choice	Pre-test	Post-test	Pre-test	Post-test
A	11	9	14	9
B	9	10	10	7
C	10	12	11	6
D*	64	63	63	76

that the four different kinds of fish all live on sea floor by selecting C in Question 18 (shown as Table 5):

18. 【　　　】 Which of the following statements about fish is **correct**?

A. Sharks and stingrays live on sea floor.

B. Sea horses float in the middle of the ocean.

C. Sharks, stingrays, clownfish, and sea horses all live on sea floor.

D. Clownfish lives in the same area as sea anemones'.

Due to the distractors B and C which drew additional responses after reading the fish in a natural setting (Figure 5), the control group had fewer correct answers than the treatment group. Actually, the habitation of shark, stingray, clownfish, and seahorse is less likely to gather together as depicted by Figure 5. In contrast, there is no visual representation in the treatment diagram guiding the participants to select B and C.

As indicated by Table 1, the variable of visual design with explicit visual cues was not always significant in our study. The arrows in Set 3 are not significant in facilitating the functional comprehension of the energy pyramid. Though the treatment group scored higher than the control group in the functional relations of the ecosystem, the difference is not significant. As for the structural relations related to the food chain, the comprehension in the two groups was very similar. The following question 41 and Table 6 offer an example to illustrate that the scores between groups were very close:

41. 【　　　】 Which of the following is the direction of energy transfer in energy pyramids?

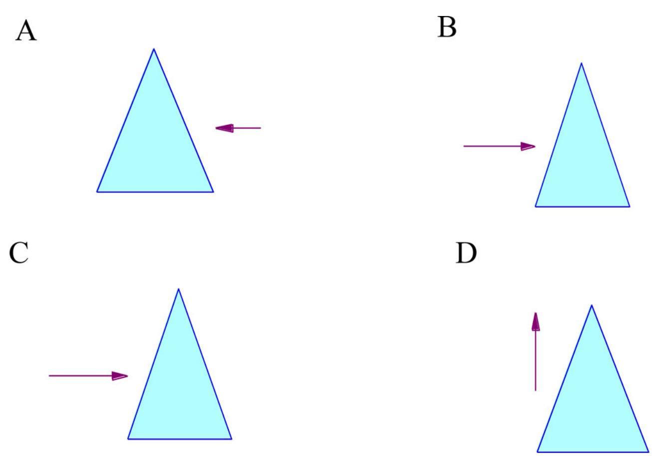


Table 6. The change of response in answering question #41.

	Control group		Treatment group	
Choice	Pre-test	Post-test	Pre-test	Post-test
A	5	0	2	1
B	3	3	2	6
C	20	5	20	4
D*	66	86	74	87

According to Table 6, 86 participants in the control group selected the correct answer in contrast to 83 in treatment group. The requirement to answer this question demanded the comprehension of the interactive relations of predators and prey in the food chain. In the treatment diagram, Figure 8, all the arrows can be classified as the cues indicating how energy flows in three paths in the ecosystem: first, the yellow arrow indicates the energy path from solar to the producer; second, the red arrows represent the direction of energy flow from the producer to the tertiary consumer in the food chain; and third, the orange arrows stand for the heat loss from the food chain to the environment. The success of the control group in Question 41 suggests that the red arrows are unnecessary. The analysis of the third path cued by orange arrows also results in a similar suggestion to that for Question 41 and Table 6. Only the existence of the first path is justified by the reader response from Question 38:

38. 【 】 Which of the following is the source energy for a stable ecosystem?

A. water

B. sunlight

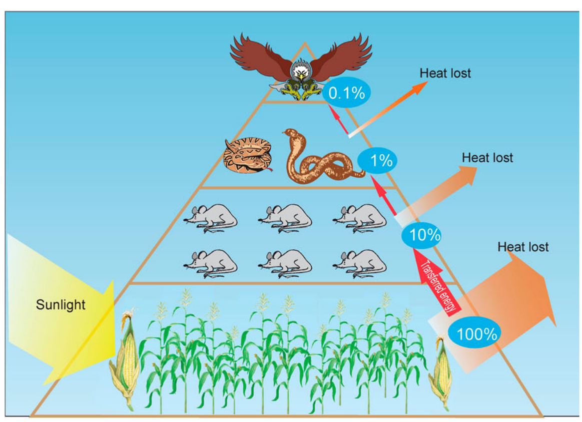
C. wind

D. minerals

Energy pyramids

The energy in consumers' food is transferred along the food chain. In the process of energy transfer, most of the energy from producers is lost and becomes heat. Only about 10% of the energy is transferred from producers to consumers. When energy is transferred to the fourth or fifth level of consumers, only a small amount is left. Food chains are therefore usually not long.

In an ecosystem, the amount of energy produced from primary producers to support primary consumers must be the greatest in a food chain. As energy is lost progressively along the food chain, the amount of energy in the consumers at different levels is progressively reduced. This means that the consumers at the top level have the least amount of energy. The order of different amount of energy at different levels in a food chain can be represented through a diagram with the shape of a pyramid (wide at the bottom and narrow at the top). This is called an energy pyramid.



An energy pyramid

Figure 8. The reading material of energy pyramid in Set 3 for the treatment group (revised from Chen et al., 2013, pp. 148–149).

Table 7. The change of response in answering question #38.

	Control group		Treatment group	
Choice	Pre-test	Post-test	Pre-test	Post-test
A	37	29	42	13
B*	37	53	36	74
C	2	4	1	1
D	18	8	19	10

Based on Table 7, the selection of answer B required an understanding of which energy triggered the energy pyramid. The treatment image (Figure 8) offering the yellow arrow marked with 'sunlight' was an explicit cue. In contrast, both the control image and verbal text did not represent any relevant information. As novice learners, our participants were not able to imagine what the resource of energy flow would be if there is no information to draw from. Therefore, this visual cue is indispensable and significant.

Meanwhile, the other two kinds of arrows appeared to be less necessary according to Tables 1 and 6. Since the prior knowledge of the relationships between predator and prey represented by the red arrows which have been already built in primary school reduced the difference between groups. The idea of heat loss represented by the orange arrows was easy to retrieve from the verbal text. Therefore, the absence of orange arrows in the control group resulted in there being little difference in responses from the treatment group. The influence of sufficient prior knowledge suggests a very mild effect of arrow cues in Figure 8.

However, this quantitative result did not agree with the qualitative study by Heiser and Tversky (2006) which confirmed that the arrow could help people interpreting mechanical system diagrams by conveying more functional descriptions about a car brake or a bicycle pump. With respect to our qualitative data from the short-answer question, the result was in line with the previous finding that the treatment group used more transitive verbs and verbs of motion in describing the mechanical operation (Hegarty & Just, 1993). It is true that our treatment group also used much more of the same kind of verbs in describing the diagram of the energy pyramid with arrows (Figure 8), such as 'transfer', 'lose', 'process', 'decrease', 'gain', 'deliver', and 'provide'. Though the control group also used these verbs, the percentage per person is 39.4% versus 69.4% in the treatment group.

Table 8. The result of ANCOVA in each cognitive process dimension.

	Control group Mean (SD)	Treatment group Mean (SD)	*F* value	Effect size
1. *Classification system*				
Remember	9.22 (3.88)	11.39 (4.27)	18.71**	.53
Understand	6.61 (2.39)	7.32 (2.49)	5.10*	.29
Apply	5.55 (2.34)	5.64 (2.39)	0.01	
2. *Fish taxonomy*				
Remember	3.77 (1.31)	4.31 (1.16)	10.70**	.44
Understand	2.13 (0.95)	2.33 (0.87)	2.71	
Apply	0.56 (0.50)	0.69 (0.46)	3.74	
3. *Energy pyramid*				
Remember	3.91 (1.43)	4.11 (1.57)	0.71	
Understand	2.45 (1.21)	2.49 (1.19)	0.02	
Apply	2.24 (1.13)	2.32 (0.96)	0.14	

*$p < .05$.
**$p < .01$.

The cognitive level favoured by the treatment design

In addition to the detailed examination about which key concept was favoured by the treatment design, an analysis of cognitive level was also necessary to further understand the characteristics of the reformatted images. According to our classification, the test questions could be identified into three levels: memory, understanding, and application. Therefore, the responses were statistically tested by analysis of covariance (ANCOVA) with respect to the three cognitive levels (shown as Table 8).

The result revealed that both the treatment diagrams with explicit tree structure from Set 1 and Set 2 cued a more basic level of cognitive comprehension. The arrows in Set 3 made no difference in cueing any cognitive level of comprehension.

The impact of prior knowledge

With regard to the covariate, prior knowledge, the effect is significant in all the three sets. With an alpha level of 0.01, which is used in the following statistical tests, $F_{\text{set 1}}$ (2, 186) = 74.35, $F_{\text{set 2}}$ (2, 186) = 38.96, and $F_{\text{set 3}}$ (2, 186) = 53.26. The data showed that these reading materials were significantly helpful in answering the questions. A further examination as to whether the difference in prior knowledge would have different learning result from the significant treatment design was tested by ANCOVA (shown as Table 9). The participants of the top-27th percentile (high level of prior knowledge) and bottom-27th percentile (high level of prior knowledge) were compared to determine whether meaningful differences existed.

The role of diagrams was very different for low and high prior knowledge students. According to Table 9, presenting the treatment images was not always beneficial for every participants though both tree-structured diagrams have been verified as significantly efficient in cueing comprehension. Only high prior knowledge participants get benefits from both. For those low prior knowledge participants, the classification system diagram could not cue better than the textbook diagram. For them, only the diagram of tree-structured fish taxonomy was beneficial.

According to diSessa (2004) and Cook et al. (2008), low prior knowledge students tended to focus on surface visual features and have little ability to integrate the features of multiple representations to construct deeper meanings. The major difference between these two diagrams was that the composition in which fish taxonomy diagram was much simpler than the classification system diagram. Hence, the surface features in the tree-structured fish taxonomy were fewer so that the concept formation requiring multiple representation integration was easier. Actually, the concept of fish taxonomy could be regarded as one branch embedded in the tree of classification system. The comprehension

Table 9. The result of ANCOVA with respect to different levels of prior knowledge in Set 1 and Set 2.

	Control group Mean (SD)	Treatment group Mean (SD)	*F* value	Effect size
1. *Classification system*				
Low	10.04 (2.81)	11.26 (4.00)	0.51	.35
High	20.72 (5.19)	23.30 (5.02)	5.78*	.49
2. *Fish taxonomy*				
Low	4.54 (2.08)	5.81 (2.00)	6.28*	.62
High	7.76 (1.56)	8.56 (0.75)	4.80*	.65

*$p < .05$.

difference resulting from prior knowledge helped us to confirm the effects of explicit tree structure in considering the condition of learners' prior knowledge.

Conclusion and implications

Intuitively explicit visual cues seem a promising solution to the reading difficulty caused by inappropriate image design. In this study, three biological textbook diagrams were reformatted according to the cognitive principles of visual design (Hegarty, 2011; Heiser & Tversky, 2006; de Koning et al., 2009; Mayer, 1992; Shah et al., 1999). The first two diagrams involving classification adopted tree structure to replace boxes or natural setting in order to exactly externalise the internal knowledge structure. The third diagram used arrows to luminate the direction of energy flow in an energy pyramid. Since our participants were novice learners in the relevant knowledge field, the comprehension was expected to be maximised by reducing the unnecessary details and colours and minimising the inferential processes.

Through the large-scale reading test, our finding suggests that not all explicit visual cues are significant in facilitating better knowledge construction. For the taxonomic diagrams, explicit tree structure is efficient in cueing hierarchical concepts but limited by learners' prior knowledge. This finding agrees with Körner (2005) and Novick and Catley (2007) particularly on the issue of readers' prior knowledge. For high prior knowledge learners, the effect is confirmed. For low prior knowledge learners, however, the efficiency depends on the diagram composition. If the composition is simple and concepts involved are easily to be integrated, then very possibly the knowledge acquisition will be enhanced by the tree structure. But if the diagram is as complicated as the classification system, then the low prior knowledge learners will have little hope of conquering the coordination of the multiple representations to make meanings.

In contrast, the effect of arrows as an explicit visual cue in reading energy pyramid diagrams is not confirmed. This finding does not agree with previous studies (Beck, 1984; Heiser & Tversky, 2006). One of the potential reasons why our finding disagreed with Heiser and Tversky (2006) was also related to the prior knowledge of food chain underlying the energy pyramid. The acquired food chain knowledge reduced the need for visual cues. Moreover, the reformation of the energy pyramid was mild because the treatment image still used the original structure which represented the food chain in a levelled pyramid. However, the first two taxonomic diagrams had undergone a radical structural change in the image reformation. The original structures such as boxes and natural setting with no visual cues were completely transformed into the tree structure which was more consistent with the current scientific paradigm. It is speculated that since the extent of reformation in the taxonomic images was much greater than the energy pyramid, this might be a cause of the different effects of explicit visual cues between tree structure and arrows.

The greatest achievement made by the tree-structure diagrams is successfully representing the qualitative class-inclusive relations and parallel relations at the same hierarchical level. This finding offers useful advice for textbook editors in designing taxonomic images. According to our previous studies, many taxonomic images in textbooks were represented by implicit cues (Ge et al., in press-b), such as the fish taxonomy in Figure 5, which might lead to less efficient comprehension. Our reformatted taxonomic images will be suitable for novice learners because the basic cognitive effect of remembering and understanding was significant.

As a textbook image, the box diagram representing the classification system was not only less efficient, but was also responsible for generating students' misunderstandings. A potential misunderstanding was to identify the current classification system as one kingdom only, which was reflected in responses from Question 2. If students were not aware that Figure 1 was only an example to briefly represent part of the system instead of a real one, they might identify that Genus Canis consisted only of coyote and grey wolf suggested by the solid lines in the box. Another potential misunderstanding was supported by the data from Question 18. The natural setting suggested the same habitation of the four animals, which was far from being true. This finding offers solid evidence consistent with the results of our prior investigation of misunderstanding arising from image design (Ge et al., in press-a) which further recommends more caution in the future image design.

The potential misunderstandings imply the need for guidance for low prior knowledge learners. As Cook et al. (2008) argued, the need for pedagogical scaffolding of representations would not be minimised even if the design had been improved. The variable of prior knowledge was consistently significant in our tests. It confirmed that reading comprehension was highly determined by prior knowledge (Cook et al., 2008; Seufert, 2003).

Study limitation

While this study attempted to investigate the effects of different visual designs in multiple visual representations, the concern of building coherent meaning relations between visual and verbal representations has also been considered in the reformation of treatment diagrams. However, as the verbal representation was controlled, the meaning unfolded by words was not neglected throughout the study.

Implications for the design of textbook diagram

The significant effects of tree structure in cueing taxonomic relations support the recommendation of this visual design as an efficient conventional tool. However, the success of explicit tree structure was at the expense of reducing the colours which, in turn, enlarged the social distance between the diagram and viewers. Conceptually, Figure 2 was efficient but less attractive than Figure 1 because of the smaller size of animals in grey colour. Moreover, the number of animals illustrated as examples might be too many and result in a heavy cognitive load for medium and low prior knowledge learners. Recently, a substantial number of colourful and realistic photographs have emerged as the most prevalent format in science textbooks, which would directly emphasise familiarity and serve to put students at ease with what they are seeing (Kress & van Leeuwen, 2006; Lee, 2010a). For the future application of Figure 2 in textbooks, a regulation of colour and components might enhance the interpersonal relationship between the image and learners.

The different effects resulting from the explicit visual cues prompt us to be more cautious about the intuition concerning influences of visual designs. Even if we have strong intuition about the efficiency of some visual design, there is still a need to empirically evaluate the design. This study provides fruitful empirical data to validate those proposed principles for constructing effective diagrams (Fleming, 1987; Kosslyn, 2006).

Implication for pedagogy and future study

The results of this study suggest that not all images ostensibly depicting the same concept are of equivalent pedagogic value. This implies that teachers should be able to evaluate the pedagogical potential of images and select appropriate images to achieve teaching goals. In addition, how to engage students more actively in manipulating the subject material as they read is also important in terms of developing science literacy in classroom. Misconceptions could be prevented through explicit instruction of reading images.

It is recommended that future studies take account of the importance of identifying science representations in a broader sociocultural perspective. The design of visual displays is inevitably influenced by the interests of sign-makers who inevitably seek to communicate their theoretical and cultural perspectives and their values to viewers. Taiwanese sign-makers designed the first two representations in this study (shown as Figures 1, 3, and 5) which sought to depict the classification concepts in visual forms other than a tree structure. From a sociocultural perspective, the selection of one form instead of others is the result of considerations about which is the most apt and plausible at that moment (Kress & van Leeuwen, 2006). Hence, decisions about the forms of representation are strongly influenced by social conventions and constraints. Cross-cultural studies of representations in school science textbooks are recommended in order to better understand how such texts position science pedagogy in relation to conventional cultural orientations towards learning which are invisible and taken for granted within a society.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Ainsworth, S. (1999). The functions of multiple representations. *Computers & Education*, *33*, 131–152.

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, *16*, 183–198.

Andreassen, R., & Braten, I. (2010). Examining the prediction of reading comprehension on different multiple-choice tests. *Journal of Research in Reading*, *33*(3), 263–283.

Beck, C. R. (1984). Visual cueing strategies: Pictorial, textual, and combinational effects. *Educational Communication and Technology Journal*, *32*, 207–216.

Blystone, R. V., & Dettling, B. C. (1990). Visual literacy in science textbooks. In M. B. Rowe (Ed.), *What research says to the science teacher–the process of knowing* (pp. 19–40). Washington, DC: Notional Science Teachers Association.

Canham, M., & Hegarty, M. (2010). Effects of knowledge and display design on comprehension of complex graphics. *Learning and Instruction*, *20*, 155–166.

Catley, K. M., Novick, L. R., & Shade, C. K. (2010). Interpreting evolutionary diagrams: When topology and process conflict. *Journal of Reseach in Science Teaching*, *47*, 861–882.

Catley, K. M., Phillips, B. C., & Novick, L. R. (2013). Snakes and eels and dogs! Oh, my! Evaluating high school students' tree-thinking skills: An entry point to understanding evolution. *Research in Science Education*, *43*, 2327–2348.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, *8*, 293–332.

Chen, S.-H., Fang, C.-H., Yao, H., Hsu, K.-C., & Lee, T.-Y. (2010). *Science and technology 2*. Tainan: Han-Lin.

Chen, S.-H., Fang, C.-H., Yao, H., Hsu, K.-C., & Lee, T.-Y. (2013). *Science and technology 2*. Tainan: Han-Lin.
Cook, M. P. (2006). Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles. *Science Education*, *90*(6), 1073–1091.
Cook, M. P., Wiebe, E. N., & Carter, G. (2008). The influence of prior knowledge on viewing and interpreting graphics with macroscopic and molecular representations. *Science Education*, *92*, 848–867.
de Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (2009). Towards a framework for attention cueing in instructional animations: Guidelines for research and design. *Educational Psychology Review*, *21*(2), 113–140.
Deneault, J., & Ricard, M. (2005). The effect of hierarchical levels of categories on children's deductive inferences about inclusion. *International Journal of Psychology*, *40*(2), 65–79. doi:10.1080/00207590444000032
diSessa, A. A. (2004). Metarepresentations: Native competence and targets for instruction. *Cognition and Instruction*, *22*(3), 293–331.
Eilam, B. (2013). Possible constraints of visualization in biology: Challenges in learning with multiple representations. In D. F. Treagust& C.-Y. Tsui (Eds.), *Multiple representations in biological education* (pp. 55–74). London: Springer.
Enns, J. T., Austen, E. L., Di Lollo, V., Rauschenberger, R., & Yantis, S. (2001). New objects dominate luminance transients in attentional capture. *Journal of Experimental Psychology: Human Perception & Performance*, *27*, 1287–1302.
Fabrikant, S. I., Rebich-Hespanha, S., & Hegarty, M. (2010). Cognitively inspired and perceptually salient graphic displays for efficient inference making. *Annals of the Association of American Geographers*, *100*, 13–29.
Fleming, M. L. (1987). Designing pictorial/verbal instruction: Some speculative extensions from research to practice. In D. A. Houghton& E. M. Willows (Eds.), *The psychology of illustration volume 2 – instructional issues* (Vol. 2, pp. 136–157). New York, NY: Springer-Verlag.
Gentner, D., & Markmann, A. B. (1997). Structure mapping in analogy and similarity. *American Psychologist*, *25*, 45–56.
Ge, Y.-P., Unsworth, L., Wang, K.-H., & Chang, H.-P. (in press-a). Image design for enhancing science learning: Helping students build taxonomic meanings with salient tree structure images. In K.-S. T. A. K. Danielsson (Ed.), *Global developments in literacy research for science education*. Springer.
Ge, Y.-P., Unsworth, L., Wang, K.-H., & Chang, H.-P. (in press-b). What images reveal: A cross-national comparison of Australian and Taiwanese junior high school science textbooks. *Research in Science Education*. doi:10.1007/s11165–016–9608–9
Hegarty, M. (2011). The cognitive science of visual-spatial displays: Implications for design. *Topics in Cognitive Science*, *3*, 446–474.
Hegarty, M., & Just, M. A. (1993). Constructing mental models of machines from texts and diagrams. *Journal of Memory and Language*, *32*, 717–742.
Heiser, J., & Tversky, B. (2006). Arrows in comprehending and producing mechanical diagrams. *Cognitive Science*, *30*, 581–592.
He, Q., & Tymms, P. (2005). A computer-assisted test design and diagnosis system for use by classroom teachers. *Journal of Computer Assisted Learning*, *21*, 419–429.
Hmelo-Silver, C. E., & Azevedo, R. (2006). Understanding complex systems: Some core challenges. *The Journal of the Learning Sciences*, *15*(1), 53–61.
Ifenthaler, D. (2010). Relational, structural, and semantic analysis of graphical representations and concept maps. *Educational Technology Research and Development*, *58*, 81–97.
Jennings, T., & Dwyer, F. (1985). The instructional effect of differential cueing strategies in facilitating student achievement of different educational objectives. *International Journal of Instructional Media*, *12*, 8–20.
Korner, C. (2005). Concepts and misconceptions in comprehension of hierarchical graphs. *Learning and Instruction*, *15*, 281–296.

Kosslyn, S. M. (2006). *Graph design for the eye and mind*. New York, NY: Oxford University Press.
Kozma, R. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. *Learning and Instruction*, *13*(2), 205–226.
Krathwohl, D. R. (2002). A revision of bloom's taxonomy: An overview. *Theory into Practice*, *41*(4), 212–218.
Kress, G., & van Leeuwen, T. (2006). *Reading images : The grammar of visual design* (2nd ed.). New York, NY: Routledge.
Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science*, *11*, 65–99.
Lee, V. R. (2010a). Adaptations and continuities in the use and design of visual representations in US middle school science textbooks. *International Joural of Science Education*, *32*(8), 1099–1126.
Lee, V. R. (2010b). How different variants of orbit diagrams influence student explanations of the seasons. *Science Education*, *94*, 985–1007.
Lin, Y.-Ch., Lee, Ch.-Sh., Huang, N.-T., Chang, Y.-T., & Tsai, Sh.-F. (2010). *Science and technology 2*. Taipei: Kan-Shen.
Mayer, R. E. (1992). *Thinking, problem solving, cognition* (2nd ed.). New York, NY: W. H. Freeman.
Mayer, R. E. (2001). *Multimedia learning.*Cambridge: Cambridge University Press.
Novick, L. R. (2001). Spatial diagrams: Key instruments in the toolbox for thought. In D. L. Medin (Ed.), *The psychology of learning and motivation* (Vol. 40, pp. 279–325). San Diego, CA: Academic Press.
Novick, L. R., & Catley, K. M. (2007). Understanding phylogenies in biology: The influence of a gestalt perceptual principle. *Journal of Experimental Psychology: Applied*, *13*(4), 197–223.
Patrick, M. D., Carter, G., & Wiebe, E. N. (2005). Visual representations of DNA replication: Middle grades students' perceptions and interpretations. *Journal of Science Education and Technology*, *14*(3), 353–365.
Peeck, J. (1993). Increasing picture effects in learning from illustrated text. *Learning and Instruction*, *3*, 227–238.
Pinto, R., & Ametller, J. (2002). Students' difficulties in reading images. Comparing results from four national research groups. *International Joural of Science Education*, *24*(3), 333–341.
Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representation. *Learning and Instruction*, *13*, 141–156.
Schnotz, W., & Lowe, R. (2003). External and internal representations in multimedia learning. *Learning and Instruction*, *13*, 117–123.
Seufert, T. (2003). Supporting coherence formation in learning from multiple representations. *Learning and Instruction*, *13*, 227–237.
Shah, P., Hegarty, M., & Mayer, R. E. (1999). Graphs as aids to knowledge construction: Signaling techniques for guiding the process of graph comprehension. *Journal of Educational Psychology*, *91*, 690–702.
Stern, L., & Roseman, J. E. (2004). Can middle-school science textbooks help students learn important ideas? Findings from project 2061's curriculum evaluation study: Life science. *Journal of Research in Science Teaching*, *41*(6), 538–568.
Stylianidou, F., & Ogborn, F. (2002). Analysis of science textbook pictures about energy and pupils' readings of them. *International Journal of Science Education*, *24*(3), 257–283.
Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*, 251–296.
Tversky, B. (2011). Visualizing thought. *Topics in Cognitive Science*, *3*, 499–535.
Tversky, B., Heiser, J., Lozano, S., MacKenzie, R., & Morrison, J. (2007). Enriching animations. In R. Lowe & W. Schnotz (Eds.), *Learning with animation* (pp. 263–285). Cambridge: Cambridge University Press.
Unsworth, L. (2001). *Teaching multiliteracies across the curriculum-changing contexts of text and image in classroom practice*. Philadelphia, PA: Open University Press.

Appendix. The rubric for the short-answer questions

1. Write down all the categories of grey wolf in the biological classification system.

Score	Criteria
7	In pre-test: as long as the answers touch the terms of classification system, for example, 'kingdom' instead of 'Animalia', the point is gained; wrong spelling is ok in post-test: the answer of seven terms has to be the Latin ones appearing on the image
6	Six categories are correct
5	Five categories are correct
4	Four categories are correct
3	Three categories are correct
2	Two categories are correct
1	One category is correct
0	None of the answers is correct

22. Please describe the meaning of this energy pyramid (Please type your answer).

Score	Criteria
1	Any description involves interactions between living things and ecosystem/reason why there are not many levels in a pyramid
1	Energy loss
2	(More general) the energy becomes less during transference
1	Mention the amount of energy transference
2	(more general) Energy is delivered/transferred/travelled /or the flow of energy
1	Transferring direction – from producers to consumers/between food chain
1	The resource of energy in ecosystem
1	Identify producer and consumer (able to differentiate the identity of member in the ecosystem)
0	Food chain in which no energy is involved