Cogent Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oaed20

Content analysis of visual representations in biology textbooks across selected educational boards from Asia

Parthasarathy J & Premalatha T |

To cite this article: Parthasarathy J & Premalatha T | (2022) Content analysis of visual representations in biology textbooks across selected educational boards from Asia, Cogent Education, 9:1, 2057002, DOI: 10.1080/2331186X.2022.2057002

To link to this article: https://doi.org/10.1080/2331186X.2022.2057002

© 2022 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

Published online: 31 Mar 2022.

Submit your article to this journal

Article views: 720

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=oaed20

J & T, *Cogent Education* (2022), 9: 2057002
https://doi.org/10.1080/2331186X.2022.2057002

cogent education

CURRICULUM & TEACHING STUDIES | RESEARCH ARTICLE

Content analysis of visual representations in biology textbooks across selected educational boards from Asia

Parthasarathy J[1*] and Premalatha T[2]

Received: 17 March 2021
Accepted: 13 February 2022

*Corresponding author:
Parthasarathy J, Department of Education, Bharathiar University, Coimbatore 641 046, India
E-mail: parthajagan007@gmail.com

Reviewing editor:
Li Zhao, School of Education Science, Nanjing Normal University, Nanjing, Jiangsu, CHINA

Additional information is available at the end of the article

Abstract: The aim of the present study was to explore the nature of visual representations in biology textbooks across five educational boards across Asia through quantitative and qualitative content analysis. Descriptive statistics was used during the quantitative analysis. Qualitative content analysis involved a deductive approach where visuals in these textbooks were examined and categorized into different categories based on a newly developed typology and taxonomy of visual representation (coding scheme). Under this newly developed typology and taxonomy (coding scheme), visuals in biology textbooks can be categorized into 19 different categories. The findings of the study summarized the characteristics of visual representation usage in these textbooks in terms of their prevalence, distributional differences and trends. Through this study, a new perspective on the taxonomy and classification of visual representations, especially for biology textbooks, has been proposed. Biology teachers and textbook authors can gain insights through the findings of the study.

Subjects: General Science; Biology; Secondary Education

Keywords: Biology textbook; content analysis; educational board; science education; visual representation

Parthasarathy J

ABOUT THE AUTHOR

Parthasarathy J has been teaching Biology in a Government School in Tamil Nadu, India, for almost a decade. Prior to this, he has taught biology to the students pursuing IBDP, AS-A Level and CBSE in India and Abroad. His voluminous teaching experience spanning for over fifteen years has been resourceful in conducting educational research in the following domains, namely, textbook, curriculum and pedagogy. He is of the opinion that at high school level, biology is primarily taught by content-based teaching method. This method prioritizes factual understanding where transfer of knowledge is highly limited. In order to ensure conceptual clarity as well as high transfer of knowledge, he emphasizes that biology should be taught using concept-based teaching instead of content-based teaching. The research article presented here primarily focuses on in-depth analysis, understanding and categorization of visual representations used in biological textbooks for grades 11 and 12.

PUBLIC INTEREST STATEMENT

Visual representations or diagrammatic illustrations occupy a significant part of science textbooks, especially biology. Visual representations are simplified representations of complex phenomena, which are not observable in other ways. The sole objective of visual representations is to engage learners in meaningful learning of complex and abstract concepts. These representations are also part of everyday teaching. In the present study, visual representations in biology textbooks across five educational boards across Asia have been analyzed and categorized based on a newly developed coding scheme. Under this new coding scheme, biological illustrations or visual representations can be categorized into 19 different categories. The understanding of these different categories of visual representations would be highly resourceful for teachers and textbook writers.

cogent oa

© 2022 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

1. Introduction

Visual representations in biology textbooks serve as a tool for conceptual change. They are critical in conveying abstract and concrete information. Many science teachers use visuals in their teaching and these visuals enhance students' understanding in many ways. Complex scientific and biological phenomena can be presented to the learner through well-illustrated diagrams. The amount of cognitive effort needed to comprehend and solve science problems can be drastically reduced through the use of illustrations. Ambiguities over textual explanation of science phenomenon can be reduced with the help of visual representations. The causal relationships and complexities prevailing in natural phenomena are best described through vivid visual representations and coherent scientific explanations. Research on visual representations in biology education is a continuous process. The research may focus on cognition of the visuals by the learner or it may focus on the role of cultural and social practice where textbooks are perceived as cultural objects. Visual representations can be used to evaluate the learners' conceptual learning through their interpretations. Previous studies on visual representation were centered on primary science textbooks (Khine & Liu, 2016) and secondary science textbooks (Liu & Treagust, 2013). The diagrammatic typologies used in all these studies are that of Hegarty et al. (1991), Leivas Pozzer and Roth (2003), and Novick (2006). Despite previous studies on primary and science textbooks, only a few studies have focused on the study of visual representation in biology textbooks of different educational boards. This study aims to find out the distribution patterns of various visual representation categories in biology textbooks across five educational boards and it has identified and described other categories of visuals that have not been reported in the diagrammatic typologies of Hegarty et al. (1991), Leivas Pozzer and Roth (2003), and Novick (2006).

1.1. Rationale and purpose

Textbooks serve as the intended curriculum taught in a large majority of biology classes. The biology curriculum at the secondary level provides the foundation for the tertiary-level learning of professional subjects like medicine, nursing, agriculture, veterinary science, fisheries and animal husbandry. Therefore, the critical analysis of biology textbooks will benefit content developers, curriculum developers and textbook writers in improving the quality of biology textbooks across different educational boards. It is widely believed that a well designed and visual-friendly biology textbook will benefit students to avoid scientific misconceptions in biology. Through this study, the researchers aim to explore the inherent properties of visual representations in biology textbooks. This study examined and categorized visuals in biology textbooks into different categories based on a newly developed typology and taxonomy of visual representation.

2. Literature review

Visuals serve as effective tools for learning. Visual representations promote learners' self-explanation. Apart from this, visuals also bring about inference generation, information integration and reduction in comprehension errors. The comparison of sentence processing and diagram processing models reveals that clustering and placement of components in diagrams have relevance in information processing. On the contrary, many studies report the difficulties involved with interpretation of visual representations or diagrams (Mathai & Ramadas, 2009). Since visuals depict scientific phenomena and processes invisible to the naked eye, understanding them is a demanding task (Liu & Treagust, 2013). Hurley and Novick (2010) have reported that students have difficulties interpreting illustrations in the textbooks. Novick (2006) reveals that science textbooks with visual-friendly representations facilitate the interpretation of domain knowledge. Visuals help learners establish familiar relationships between a well-known domain and a new one leading to constructivistic learning and analogical reasoning (Newton, 2003). Students should be provided with illustration-related tasks, and they should be allowed to work on them. It was reported that textbook learning efficacy can be improved by augmenting text with more visual elements (Agrawal et al., 2011). There exists a parallel relationship between textual content and visuals where both represent the same information but with varying levels of appeal. The significance of integrating textual content and visuals in introducing abstract science concepts has been established by Vinisha and Ramadas (2013). Difficulties in interpreting visuals arise when

multiple conventions such as colour coding, real or broken line and arrows are used without explanations (Leivas Pozzer & Roth, 2003). Carvalho et al. (2011) reported that textbooks of European countries tend to have more textual content than images in their textbooks, whereas the vice-versa is noticed in Non-European Textbooks. Slough et al. (2010) report that graphical representations in 6th grade science textbooks in the USA fulfill only decorative roles, and they are mostly unrelated to textual content.

2.1. Theoretical framework

The end product of teaching and learning processes in biology is conceptual change. The process where concepts and relationships between the concepts change over the course of an individual's (learner's) lifetime is called conceptual change. It means restructuring of one's existing knowledge and beliefs. Conceptual change in an individual depends on active engagement and prior knowledge of the learner. The role of prior knowledge or what the learner already knows in learning is stressed in Ausbel's Theory of Meaningful Learning (Gagné, 1969). This differentiates meaningful learning from rote learning. The Ausbel's Theory is a drastic shift from Jean Piaget's Theory of Cognitive Development (Piaget, 1964) and Vygotsky's Socio-cultural Theory (Vygotsky, 1980). Visual representations also influence conceptualization of knowledge. The study present here considers visual representation as a constructive learning tool that facilitates the process of conceptual change in the learner.

2.2. Research questions

The study is aimed to examine the nature and extent of the use of visual representations in biology textbooks for years 16 to 19 prescribed for five educational boards in Asia. Data about the visuals in these books were used to respond to the following research questions:

(1) How are the different categories of visual representations distributed in the five different textbooks?

(2) How are the different categories of visual representations distributed within the different chapters across each textbook?

(3) How are the different categories of visual representations distributed within each of the selected biology textbooks?

3. Methodology

3.1. Analysis procedure

This research study was carried out using a research method called content analysis. In this method, data collection was done through qualitative content analysis and quantitative content analysis. Qualitative Content Analysis was carried out using a deductive approach where data collection was done using pre-determined codes and categories as given in the coding scheme. This was followed by Quantitative Content Analysis, which involved frequency counts of visuals under the different categories of visual representations. The distributions under each category were computed using descriptive statistics, namely percentage and mean. The analysis involved the following steps:

Step-1: Formulation of categories for visual representation.

Step-2: Formulation of rules of coding for each of these categories.

Step-3: Consolidation of all the categories for each of these dimensions and their rules of coding into a Coding Scheme. As a result, a Coding Scheme for Visual Representations was generated and this was used as the basic tool in this study.

Step-4: As part of the qualitative analysis, the documents (textbooks) were worked through using the Coding Schemes for the various dimensions.

Step-5: As part of the quantitative analysis, collection of frequency counts of visuals under each category was done.

Step-6: Descriptive statistics such as percentage and mean were used to analyze the frequency counts.

Step-7: Analysis and interpretation of the data.

3.2. Sample

Biology textbooks from five different educational boards were selected as a sample in this study. The details about the various educational boards (from India and followed in many Asian countries) considered in this study are shown in Table 1. The curriculum structure of these educational boards is summarized in Table 2. These textbooks were designed for two-year secondary schooling for the age groups between 16 and 19. The descriptions of the textbooks included in this study are shown in Table 3. The general characters of the textbooks in terms of the total number of pages, narration pages, chapters, words, visual representations, mean of the chapters in terms of number of words, number of sentences, visual representations per page and visual representations per chapter are provided in Table 4.

3.3. Coding scheme

The coding scheme for the coding of visual representations in science textbooks is usually based on the different typologies as proposed by Hegarty et al. (1991), Leivas Pozzer and Roth (2003), and Novick (2006). According to Hegarty et al. (1991) visual representations or diagrams in science textbooks are categorized into three types, namely, Iconic, Schematic and Charts & Graph. To these three categories, a recent category called Augmented Reality was added by Novick (2006), extending the number to four. Leivas Pozzer and Roth (2003) categorized illustrations in science textbooks into five categories—Photographs, Naturalistic Drawings, Maps & Diagrams, Graphs & Tables and Equations. Biology textbooks are made of many other categories of visuals other than those mentioned in the above typologies, and therefore categorization based on these typologies will not make the classification exhaustive. For example, visuals such as cryo-electromicrograph images, molecular visualization software generated images, computer generated images, space-filling model images, photomicrographs, genetic crosses, pedigree charts, phylogenetic trees, cladograms, symbolic equations, structural formulae and biological process diagrams can nowhere be placed under any of the above mentioned categories. Therefore, the researchers felt the need to develop a new typology and taxonomy for categorizing the visuals in biology textbooks. The coding scheme used in this study is based on this new typology and taxonomy, which is appropriate for biology textbooks. Under the new typology and taxonomy, visual representations in biology textbooks can be categorized into 19 different categories. Table 5 represents the categories of visual representations under the new coding scheme used in this study. The definitions and meanings of these categories are provided under the rules of coding.

3.4. Validity

The validity of the categories and the rules of coding as enumerated in the Coding Scheme for visual representations were validated through consultation with experts and academic professionals in the domain of biology in India and abroad.

3.5. Reliability

To establish reliability, this study was done by two evaluators in a parallel fashion. The first evaluator was the researcher himself and the second evaluator was a subject expert with more than fifteen years of experience in biology textbook analysis experience. Based on the self-developed coding scheme for visual representations, the two evaluators independently analyzed the manifest content of the textbooks in three cycles and their level of consistency among them was determined by comparing their classifications with each other. A reliability analysis was

Table 1. Details about the educational boards mentioned in this study

S.No	Educational Board (Curriculum)	Nature of the Board	Year of establishment	Apex body in the preparation of Curriculum and Syllabus	Name of the Examination for age groups 16–19 years	List of countries offering the educational board in Asia
1.	Central Board of Secondary Education (CBSE)	National Board of School Education in India	1952 (reconstituted in 1962)	National Council of Educational Research and Training (NCERT) based on National Curriculum Framework (NCF) 2005 (now replaced by NPE 2020)	All India Senior Secondary School Examination	Afghanistan, Bahrain, Bangladesh,Burma, India, Indonesia,Iran, Japan, Kuwait, Malaysia, Oman, Qatar, Saudi Arabia, Singapore, Thailand, UAE
2.	Tamil Nadu State Board of Education(TN Board)	State Board of School Education, in Tamil Nadu	1910	State Council of Educational Research and Training (SCERT), Tamil Nadu based on Tamil Nadu Curriculum Framework (TNCF) 2017	Tamil Nadu Board of Higher Secondary Education	Tamil Nadu(a state in the Indian subcontinent)
3.	International Baccalaureate (IB) (previously International Baccalaureate Organization—IBO) Diploma Programme (IBDP)	Private Board(Geneva, Switzerland)	1968	International Baccalaureate (IB)	International Baccalaureate Diploma Programme Examination (Standard Level/Higher Level)	Bahrain, Bangladesh, China, Hongkong, India, Indonesia, Japan, Kuwait, Malaysia, Pakistan, Singapore, Srilanka, Thailand, UAE, Vietnam
4.	Cambridge Assessment International Examination (CAIE) (previously Cambridge International Examinations—CIE) Advanced Subsidiary—Advanced (AS-A) Level	University of Cambridge, United Kingdom	1858	Cambridge Assessments (University of Cambridge Local Examinations Syndicate) Non-teaching Department of the University of Cambridge	Advanced Subsidiary—Advanced (AS-A) Level Examination	Afghanistan, Bahrain, Bangladesh,Burma, China, India, IndonesiaIran, Japan, Kuwait, Malaysia, Oman, Pakistan, Qatar, Saudi Arabia, Singapore, Thailand, UAE, Vietnam
5.	Advanced Placements (AP Board)	Private Board (New York City, United States of America)	1955	AP board	Advanced Placement Examinations	Bahrain, China, India, IndonesiaIran, Japan, Kuwait, Malaysia, Oman, Pakistan, Qatar, Saudi Arabia, Singapore, Thailand, UAE.

cogent education

Table 2. Details about the curriculum objectives and curriculum framework of the educational boards mentioned in this study

Educational Board (Curriculum)/ Objectives/ Framework/ Duration
Educational Board: Central Board of Secondary Education (CBSE). **Curriculum Objectives**: Encourages learners to achieve cognitive, affective and psychomotor excellence; Encourages learners to enhance self-awareness and explore innate potential; Promotes Life Skills, goal setting, and lifelong learning in learners. Inculcates values and foster cultural learning and international understanding in an inter dependent society; Encourages learners to acquire the ability to utilize technology and information for the betterment of humankind; Encourages learners to strengthen knowledge and attitude related to livelihood skills; Encourages learners to develop the ability to appreciate art and show case talents; Promotes physical fitness, health and well-being. Promotes arts integrated learning. **Curriculum Framework**: The curriculum encompasses seven major learning areas, which are: Languages, Humanities, Mathematics, Science and Technology, Skill Subjects, General Studies. and Health and Physical Education. These areas are broadly divided into Scholastic areas include Languages, Academic Electives and Skill Subjects and Co-scholastic areas include General Studies, Health and Physical Education. The curriculum encourages the study of 6 subjects (One Core Language + 4 Compulsory Subjects (Academic or Vocational) + One Elective). Core Language is compulsory for all students. Apart from Core Language, the students chose four subjects based on the stream which they are interested in. The 6th subject is always an elective. **Duration**: 2 Years
Educational Board: Tamil Nadu State Board of Education. **Curriculum Objectives**: Encourages learners to: develop ethical character, achieve the character of secularism and democratism, develop into a good citizen, be a worthy member of the home, maintain good physical health, provide training in leadership, inculcate dignity of labor, play individual attention to mould the pupils with courageous minds, soft hearts and to make each one good and intelligent, allow full scope for the development of personality so as to facilitate specialization through suitable creative work. **Curriculum Framework**: The curriculum encourages compulsorily study 6 subjects English Language, Second Language and 4 Subjects (These 4 subjects can be chosen from Academic Core Subjects or Vocational Core Subjects). **Duration**: 2 Years
Educational Board: International Baccalaureate (IB) (previously International Baccalaureate Organization—IBO). **Curriculum Objectives**: Encourage students to be knowledgeable and inquiring as well as caring and compassionate. Encourages students to develop international understanding, open-mindedness, and attitudes necessary for them to respect and evaluate a range of points of view. **Curriculum Framework**: IBDP encompasses DP Core and 6 Subject Groups. DP Core (3)—Theory of Knowledge, Extended Essay, CAS (Creativity Activity Service); Subject groups (6)—Studies in Language and Literature, Language Acquisition, Individuals and Societies, Sciences, Mathematics and The Arts. The subjects are offered both at Standard Level (SL) and at Higher Level (HL). Normally students must opt 3 subjects (and not more than 4) at HL and remaining subjects at SL. Students may opt to study an additional science, Individuals and Society, Language Courses instead of Arts. **Duration**: 2 Years.
Educational Board: Cambridge Assessment International Examination (CAIE) (previously Cambridge International Examinations—CIE). **Curriculum Objectives**: Encourages learners to be confident in working with information and ideas—their own and those of others. Encourages learner to be responsible for themselves, responsive to and respectful of others. Encourages learners to be reflective learners, developing their ability to learn. Encourages learners to be innovative and equipped for future challenges. Encourages learners to be engaged intellectually and socially ready to make a difference. **Curriculum Framework**: The curriculum offers 55 subjects and students can opt subjects of their choice. There are no compulsory subjects and students are free to specialize or study a range of subjects. Typically students take four subjects at Advanced Subsidiary Level and three subjects at Advanced Level. Occasionally exceptional students take 4 or 5 subjects at A Level This flexibility also helps school to build individualized curriculum. Students can start some subjects as AS Level and extend them to A Level also. The board doesnot obligates students to complete three subjects at a specific time. However, most students complete the exams of their three subjects all at once at the end of the course or may complete one subject after another at different stages of their studies. **Duration**: Advanced Subsidiary Level—1 Year, Advanced Level—2 Years
Educational Board: Advanced Placements (AP Board). **Curriculum Objectives**: Encourages willing and academically prepared students to pursue college-level studies while at school itself. Encourages students to learn essential time management and study skills needed for college and career success. Encourages learners to dig deeper into subjects that interest them and learn to tap their creativity and their problem-solving skills to address course challenges. **Curriculum Framework**: The AP offers 38 courses in seven subject categories modeled on a comparable introductory college course in the subject and high schools can choose what courses they would like to offer. Schools are authorized by AP Course Audit to offer approved AP courses and use the AP designation. The AP board never supplies prescribed syllabi for AP Courses but supplies detailed set of expectations that a college-level course in that subject should cover. The AP Board allows AP teachers to design their own syllabi. **Duration**:2 Years

Table 3. Description about the biology textbooks used in the study

Name of the Education Board	Age Groups	Name of the Textbook	Name of the Author(s)	Name of the Publisher	Number of Volumes	Number of Pages	Approach of presenting Biology content
International Baccalaureate Diploma Programme (IBDP)	16–19 Years	Biology Course Companion	Andrew Allot and David Mindorff	Oxford University Press, Oxford, United Kingdom	One	719	Non Segregated Approach(Biology content is not bifurcated into Botany and Zoology and the content is studied in an integrated manner
Cambridge Assessment International Examination (CAIE) Advanced Subsidiary—Advanced(AS-A) Level	16–19 Years	Biology Course Book	Mary Jones, Richard Fosbery, Jennifer Gregory, Dennis Taylor	Cambridge University Press, United Kingdom	One	696	
Advanced Placements (AP)—The College Board	16–19 Years	Biology for Advanced Placements	Julianne Zedalis, John Eggebrech	Open Stax, Rice University, Houston, Texas	One	1802	
Central Board of Secondary Education, India (CBSE)	16–19 Years	Biology Textbook for Class XI	NCERT Team of writers	NCERT, New Delhi, India	Two	342	
		Biology Textbook for Class XII				286	
Tamil Nadu State Board of Education (TN)	16–19 Years	Biology—Botany for Higher Secondary First Year	SCERT Team of writers	SCERT, Tamil Nadu, India	Four	264	Segregated Approach(Biology content is bifurcated as Biology-Botany and Biology-Zoology and the content is studied separately)
						216	
		Biology—Zoology for Higher Secondary First Year				216	
						176	
		Biology—Botany for Higher Secondary First Year			Two	264	
		Biology—Zoology for Higher Secondary First Year				256	

Table 4. General characteristics of the textbooks

S.No	General Characteristics	TN	CBSE	IBDP	AS-A	AP	Total
1.	Total Number of Pages.	1392	628	719*	696	1802	5237
2.	Total Number of Narration Pages.	806.5	569.5	389.5	439.5	1150	3355
3.	Total Number of Chapters.	49	38	11	21	38	161
4.	Total Number of Visual Representsations	1312	386	698	620	1127	4143
5.	Mean of Visual Representations per Page	0.66	0.58	1.32	0.82	0.59	-
6.	Mean of Visual Representations per Chapter	26.77	10.15	63.45	29.52	29.65	

*The IBDP has a total of 719 pages of which the 514 pages alone were analyzed in this study (SL and HL topics only)

cogent education

Table 5. Coding scheme developed and followed in this study

Name of the Category	Code	Rules for Coding
Photomicrographs	D01	Visuals showing images of microscopic objects generated by a camera. The images are usually supplemented with magnification.
Photographs	D02	Visuals showing images of macroscopic objects generated by a camera.
Iconic Diagrams (other than photograph and photomicrograph)	D03	Visuals that show an accurate depiction of concrete objects in which spatial relations in the diagram are isomorphic to those in the referent object are called Iconic Diagrams. Example: Sketches of skeletons of an Asian elephant and an African elephant.
Schematic Drawings & Naturalistic Drawings	D04	Visuals that are highly abstracted form real-world entities but only preserve the physical relationships presented in the source information is called Schematic Drawings. E.g., Chart showing Human Digestive System, Electric circuit diagrams, magnetic fields and Periodic Table. Visuals depicting realistic objects in its natural settings or its context are called Naturalistic Drawings. E.g., Visuals of Ancient Earth showing evolution.
Graphs & Charts	D05	Visuals that relationships between independent variable and dependent variable are called Graphs. Visuals showing data in the form of symbols such as bars, lines or slices are called a chart. E.g., Pie Chart, Bar Chart and Line Chart.
Maps	D05M	A visual showing an area of land or sea with physical features is called a Map. E.g., Geographic Maps.
Phylogenic Trees, Cladograms and Tree Lines	D06	Visuals that show actual representation of evolutionary relationships between different groups of animals are called an Evolutionary Tree or Phylogenetic Tree. Visuals that show a hypothetical representation of evolutionary relationships between different groups of organisms are called Cladograms.
Tables	D07	A visuals showing data or information organized in the form of rows and columns is called a Table.

(*Continued*)

cogent education

Table5. (*Continued*)

Name of the Category	Code	Rules for Coding
Equations, Symbolic Representations and Structural Formulae	D08	An Equation is defined as a symbolic representation of a relationship between variables and constants or symbolic representation of a chemical reaction. An image or a diagram showing the arrangement of atoms within the molecule is called Structural Formula.
Genetic Crosses & Pedigree Charts	D09	Visuals of Punnet Square showing genetic crosses. Chart showing inheritance of a gene from one generation to another is called Pedigree Chart.
Augmented Reality Diagramss	D10	Visuals that contain virtual reality images that were designed and produced by multimedia technology are called Augmented Reality Diagrams.
Computer Generated Images	D10C	Visuals developed by the application of computer graphics to create or contribute to images in art, printed media are called Computer Generated Images.
Cryo-EM Structural Images	D10E	Three dimensional images obtained by using Cryo-Electron Microscopes are called Cryo-EM Structural Images. This technology (blobology) is used for the study of protein molecules only. Such structures are useful for uncovering how proteins work, how they malfunction in disease and how to target them with drugs.
Molecular Visualizations Software Generated Images	D10M	Molecular Visualization Software is used to view 3D configurations of molecules and its images are 3D images of molecules.
Biological Process Diagram Transport Arrow Type	D11	Biological process diagrams with arrows that focus on “transport”. The arrows represent flow of energy or matter from one component to another. The arrows also signify a sense of movement or transport. E.g., Food chain, Food web, Diffusion.
Biological Process Diagram Causality Arrow	D12	Biological process diagrams with arrows that focus on “causality”. The arrows describe a step-by-step process where a process in one component has an effect on the next component. E.g., Flowchart, Movement from Nucleus to Cytoplasm, Endocytosis, Exocytosis.

(*Continued*)

cogent education

Table5. (*Continued*)

Name of the Category	Code	Rules for Coding
Classification Charts	D12C	Visuals explaining a classification scheme are called Classification Charts.
Biological Process Diagram Transformation Arrow Type	D13	Biological process diagrams with arrows that focus on "transformation". The arrows describe the transformation of the compartment itself (e.g., a chemical compound). The arrows of chemical reactions belong to this type. E.g., Chemical Reactions, Reactions showing Digestion.
Biological Process Diagram Feedback Arrow Type	D14	Biological process diagrams with arrows that focus on "feedback". The arrows are typically used in diagrams explaining hormonal action. The arrows represent the type of feedback—inhibition or stimulation of the hormone. The arrows may be labeled by a plus or minus sign representing the direction of the feedback. E.g., Feedback Mechanism of Hormones.

cogent education

conducted using the formula: Reliability = Agreement/(Agreement + Disagreement)X100 and for the present study it was found to be 94%.

4. Results and discussion

This study involved both qualitative content analysis and quantitative content analysis of visuals in biology textbooks of different educational boards.

4.1. Qualitative analysis

The distribution of photomicrographs in five of the textbooks is pertaining to the area of biology called "Cell Biology". The presence of photomicrographs promotes conceptual change during the learning of cells, cell organelles and cell division. The photomicrographs presented in AS-A and AP biology textbooks were captioned with magnifications. The magnification figures help the learners to understand the scale of magnification. Photomicrographs from biology textbooks on Indian boards do not show magnifications in the captions. Photomicrographs are also part of the assessment tasks in the textbooks of AS-A, IBDP and AP boards of education. All these boards stress on the numerical calculations based on photomicrographs. Various tasks include determination of magnification from a scale bar, calculation of magnification of a photograph and determination of the real size of an object from its magnification. Teaching and learning "Cell Biology" with photomicrographs promotes orientation of the learner towards research. The realistic image of cells and its organelles are realized only with the aid of micrographs, and the use of iconic diagrams is resourceful at lower levels of learning. Photographs are the most versatile visuals in textbooks. Photographs spontaneously draw the attention of the readers and convey a lot of information. Leivas Pozzer and Roth (2003) classified photographs into four different categories—photographs without captions, photographs with captions that name what can be seen, photographs with captions that name and classify what is represented, and lastly, photographs with captions that present new information. The majority of the photographs analyzed in this study are captioned. Leivas Pozzer and Roth (2003) also mention about the functional roles of photographs. Photographs may have decorative function, illustrative function, explanatory function and complementary function. In the textbooks analyzed, the biology textbooks for AP, AS-A Level, IBDP have explanatory functions, whereas those for CBSE and TN Board have illustrative function. Photographs are predominantly represented in chapters dealing with "Ecology", "Biodiversity", and "Morphology". Iconic Diagrams (other than Photograph and Photomicrograph) are found to be widely distributed in many chapters of Indian Biology Textbooks. Iconic diagrams are key forms of visual representations in biology textbooks for explaining abstract domain knowledge from physiology, organs and organ systems. Iconic Diagrams in Tamil Nadu Biology Textbooks need to be improved in terms of size and clarity. Schematic diagrams serve to explore and interpret complex information and elements in a simplified manner using symbolic and abstract lines, shapes and text to convey domain knowledge. The disadvantage of a schematic diagram lies in its over-simplified representation of the reality. Comprehension of schematic diagrams requires effective diagrammatic reading skills. Learners need to prepare mental models of the domain knowledge and the diagrammatic representation. Graphs and Charts show cross-thematic transfer of knowledge, especially from mathematics. Interpreting and drawing graphs and charts form a significant component of the assessment tasks in biology textbooks for AS-A Level, IBDP and AP. Graphs and Charts are the most intellectually demanding visuals, comprehension of which needs knowledge of conventions.

4.2. Quantitative analysis

About 4,143 visual representations of biology textbooks from five educational boards were investigated by applying content analysis and categorized into 19 different categories based on a coding scheme. Descriptive statistics was used to calculate the total number of visual representations and proportion of each diagram category in each textbook.

4.2.1. Prevalence of visual representations

Table 6 shows that out of the 4,143 visuals analyzed, the highest percentage of representation was found in the category D02 (21.5%) followed by D03 (20.6%) and D04 (15%). The lowest percentage

of representation was reported for the categories D10C and D10E (0.2% each). Mean of the frequency counts of visual representations under different categories in each of the textbooks is shown in Table 7.

4.2.2. Distribution of different categories of visual representations among the five biology textbooks *(Table 8)*

The textbooks showing the highest percentage of representation under each category are as follows: D01 in AP (31.8%), D02 in TN (31.9%), D03 in TN (30.5%), D04 in TN book (51.1%), D05 in IBDP book (36.9%), D05M in AP book (37.4%), D06 in AP (50.0%), D07 in TN (43.0%), D08 in AP book (51.3%), D09 in TN (45.0%), D10 in AP book (57.8%), D11 in AP book (35.4%). D12 in both AP and TN books (36.9% each), D12C in TN (75.0%), D13 in 46.0% in TN book and D14 category in AP (50.0%). The visuals under the categories D10C, D10E and D10M are very poorly represented. All three categories of these visuals are found only in IBDP book, whereas the first two are found in both IBDP and AS-A Level books.

4.2.3. Distribution of different categories of visuals within the different chapters of the five biology textbooks

About 8.3% of the total visuals analyzed belong to the category D01 (Photomicrographs). Of these, 31.8% are represented in AP book ("Cell Structure" 0.4%, "Viruses" 0.4%, "Plant Forms and Physiology" 0.3%), 29.8% in IBDP book ("Cell Biology" 0.7%), 29.5% in AS-A book ("Cell Structure" 0.4%), 4.3% in TN book ("Cell: The Unit of Life" 0.1%) and 3.4% in CBSE book ("Sexual Reproduction" 0.09%). Of all the different categories of visual representations, it is the D02 (Photographs) that is the most frequently used form of visual in biology textbooks. The highest representation of photographs is reported in TN book 31.9% ("Reproductive Morphology" 2.05%), followed by AP book 30.8% ("Plant Forms and Physiology" 0.8%, "Ecology and Biosphere" 0.7%), IBDP book 19.9% ("Ecology" 0.8%), AS-A book 12.7% ("Biodiversity, Classification and Conservation" 0.7%) and CBSE book 4.6% ("Morphology of Flowering Plants" 0.2%). Iconic diagrams (other than photographs and photomicrographs) categorized under D03 is found to be maximum in TN book (30.5%) (of which 0.6% in found in "Organs and Organ Systems"), 17.7% in CBSE book ("Animal Kingdom" 0.5%), 15.4% in AS-A book ("Biological Molecules" 0.4% and "Co-ordination" 0.4%) and 6% in IBDP book ("Nucleic Acids" 0.4%). 30.2% of the visuals from this category are found in AP textbook (0.5% in "The Animal Body: Basic Function"). The category D04 (Schematic diagrams and Naturalistic drawings) is found to be 51.1% in TN book ("Tissues and Tissue System" 1.06%), 1.5% in IBDP ("Human Physiology" 0.4%), 13.0% in AP ("The Musculoskeletal System" 0.3%), 11.4% in CBSE ("Morphology of Flowering Plants" 0.2%) and 8.9% in AS-A book ("Transport in Plants" 0.3%). Graphs and Charts (Category D05) are found in all the five textbooks with 36.9% representation in IBDP, 23.2% in AS-A, 18.6% in AP, 13.2% in TN and 7.9% in CBSE. Graphs and Charts are featured in the chapters "Molecular Biology" (0.4%) in IBDP, "Enzymes" (0.2%), "Planning, Analysis and Evaluation" (0.2%) in AS-A, "Population and Community Ecology" (0.26%) in AP and "Bio-molecules" (0.1%) in TN biology textbooks.

4.2.4. Distribution of different categories of visual representations within each of the selected biology textbooks *(Table 9)*

In the "Textbook of Biology for Tamil Nadu Board (TN)", the categories with a significant percentage of visual representations are D04 (24.2%), D02 (21.6%) and D03 (19.8%). Within the book "Biology for Advanced Placements", the three categories that show a significant percentage of visuals are D02 (24.3%), D03 (22.8%) and D01 (9.7%). The following categories having a significant percentage of representations in the "Biology Course Companion for IB Diploma Programme" are as follows: D02 (16.7%), D01 (14.7%), D04 (13.8%). In the "Biology Course Book for Cambridge International AS-A Level", the categories D03 (21.2%), D02 (18.1%) and D01 (16.4%) have significant percentage of visuals. Lastly in the "Textbook of Biology for CBSE", there are a significant percentage of visuals in D03 (39.3%), D04 (18.3%) and D02 (10.6%).

Table 6. Frequency counts of visual representations under different categories in the selected biology textbooks

Book	D01	D02	D03	D04	D05	D05M	D06	D07	D08	D09	D10	D10C	D10E	D10M	D11	D12	D12C	D13	D14	Total
AS-A	102	113	132	55	56	6	-	47	9	14	5	2	1	-	34	25	-	16	3	620
IBDP	103	177	51	97	89	9	7	47	21	16	5	10	8	9	25	4	3	15	2	698
AP	110	274	258	81	45	13	9	83	57	7	22	-	-	-	66	58	1	37	6	1127
CBSE	15	41	152	71	19	-	-	28	8	7	1	-	-	-	19	12	-	13	-	386
TN	15	284	261	318	32	7	2	155	16	36	4	-	-	-	42	58	12	69	1	1312
Total	**345**	**889**	**854**	**622**	**241**	**35**	**18**	**360**	**111**	**80**	**37**	**12**	**9**	**9**	**186**	**157**	**16**	**150**	**12**	**4143**
%	**8.3**	**21.5**	**20.6**	**15**	**5.9**	**0.8**	**0.4**	**8.6**	**2.6**	**1.9**	**0.9**	**0.3**	**0.2**	**0.2**	**4.5**	**3.8**	**0.4**	**3.6**	**0.3**	

https://doi.org/10.1080/2331186X.2022.2057002

Table 7. Mean of the frequency counts of visual representations under different categories in the selected biology textbooks

Book	D01	D02	D03	D04	D05	D05M	D06	D07	D08	D09	D10	D10C	D10E	D10M	D11	D12	D12C	D13	D14
AS-A	4.85	5.38	6.28	2.61	2.66	0.28	-	2.23	0.42	0.66	0.23	0.09	0.04	-	1.61	1.19	-	0.76	0.14
IBDP	9.36	16.09	4.63	8.81	8.09	0.81	0.63	4.27	1.90	1.45	0.45	0.90	0.72	0.81	2.27	0.36	0.27	1.36	0.18
AP	2.89	7.210	6.78	2.13	1.18	0.34	0.23	2.18	1.5	0.18	0.57	-	-	-	1.73	1.52	0.02	0.97	0.15
CBSE	0.39	1.07	4	1.86	0.5	-	-	0.73	0.21	0.18	0.02	-	-	-	0.5	0.31	-	0.34	-
TN	0.30	5.79	5.32	6.48	0.65	0.14	0.04	3.16	0.32	0.73	0.08	-	-	-	0.85	1.18	0.24	1.40	0.02

Table 8. Distribution of different categories of visual representations among the biology textbooks (in percentage)

Book	D01	D02	D03	D04	D05	D05M	D06	D07	D08	D09	D10	D10C	D10E	D10M	D11	D12	D12C	D13	D14
AS-A	29.6	12.7	15.4	8.8	23.2	17.1	-	13.0	8.1	17.5	15.8	16.6	11.1	-	18.3	15.9	-	10.6	25.0
IBDP	29.8	19.9	5.9	15.6	36.9	25.7	38.8	13.0	18.9	20.0	13.1	83.3	88.8	100	13.4	2.5	18.7	10.0	16.6
AP	31.9	30.8	30.2	13.0	18.7	37.1	50.0	23.0	51.3	8.7	57.9	-	-	-	35.5	36.9	6.2	24.6	50.0
CBSE	4.3	4.6	17.8	11.4	7.9	-	-	7.8	7.2	8.7	2.6	-	-	-	10.2	7.7	-	8.7	-
TN	4.3	31.9	30.6	51.1	13.2	20.0	11.1	43.0	14.4	45.0	10.5	-	-	-	22.6	36.9	75.0	46.0	8.3
Total	**99.9**	**99.9**	**99.9**	**99.9**	**99.9**	**99.9**	**99.9**	**99.8**	**99.9**	**99.9**	**99.9**	**99.9**	**99.9**	**100**	**100**	**99.9**	**99.9**	**99.9**	**99.9**

Table 9. Distribution of different categories of visual representations within each of the selected biology textbooks (in percentage)

Book	D01	D02	D03	D04	D05	D05M	D06	D07	D08	D09	D10	D10C	D10E	D10M	D11	D12	D12C	D13	D14	Total
AS-A	16.4	18.2	21.2	8.8	9.0	1.0	-	7.6	1.5	2.3	0.8	0.3	0.2	-	5.5	4.0	-	2.6	0.5	**99.9**
IBDP	14.8	25.4	7.3	13.9	12.7	1.3	1.0	6.7	3.0	2.3	0.7	1.4	1.1	1.3	3.6	0.6	0.4	2.1	0.3	**99.9**
AP	9.8	24.3	22.9	7.2	4.0	1.2	0.8	7.4	5.1	0.6	1.9	-	-	-	5.8	5.1	0.08	3.3	0.5	**99.9**
CBSE	3.9	10.6	39.4	18.4	4.9	-	-	7.2	2.1	1.8	0.2	-	-	-	4.9	3.1	-	3.4	-	**99.9**
TN	1.2	21.6	19.9	24.2	2.4	0.5	0.1	11.8	1.2	2.8	0.30	-	-	-	3.2	4.5	0.9	5.3		**99.9**

KEY: D01-Photomicrographs; D02-Photographs; D03-Iconic Diagrams (Other than Photograph and Photomicrograph); D04-Schematic Drawings& Naturalistic Drawings; D05-Graphs & Charts; D05M-Maps; D06-Phylogenic Trees, Cladograms and Tree lines; D07-Tables; D08-Equations, Symbolic Representations and Structural Formulae; D09-Genetic Crosses &Pedigree Charts; D10-Augmented Reality; D10C-Computer Generated Image; D10E-CryoEM Structural Images; D10M-Molecular Visualization Software Images; D11-Biological Process Diagram Transport Arrow Type; D12-Biological Process Diagram Causality Arrow Type; D12C-Classification Charts; D13-Biological Process Diagram Transformation Arrow Type; D14-Biological Process Diagram Feedback Arrow Type

5. Findings and intepretations

The five significant findings of qualitative content analysis pertaining to the present study are as follows: that Foreign Biology Textbooks unlike Indian Biology Textbooks have Photomicrographs that promote numerical, analytical and reasoning abilities; that Photographs of Foreign Biology Textbooks are more explanatory and illustrative in function than Indian Biology Textbooks; that Indian Biology Textbooks have greater representation of Iconic Diagrams than Foreign Biology Textbooks; that Schematic Diagrams & Naturalistic Drawings are found to be maximum representation in "Human Physiology" than other lessons and that Graphs and Charts with cross-thematic approach are represented more in Foreign Biology Textbooks than in Indian Biology Textbooks.

The four significant findings of quantitative content analysis pertaining to the present study are as follows: that out of the 4,143 visuals analyzed, the highest percentage of representation was found in the category Photographs (21.5%) followed by Iconic Diagrams (20.6%) and Schematic Diagrams (15%), whereas the lowest percentage of representation was reported for the categories D10C and D10E (0.2% each); that out of the 4,143 visual analyzed, the TN biology book had 31.6% visuals followed by AP book with 27.2%, IBDP book with 16.8%, AS-A Level book with 14.9% and CBSE book with 9.3% of visuals; that on an average, every chapter in TN book has 19.02 visuals, CBSE book has 9.6 visuals, IBDP book has 45.2 visuals, AS-A level book has 27.4 visuals and AP book has 28.0 visuals; and that the mean of visual representations per page in each of the textbooks is as follows: IBDP 1.32, AS-A Level 0.82, TN 0.66, AP 0.59 and CBSE 0.58.

6. Educational implications

The results of the content analysis of biology textbooks of five educational boards substantiate the fact that visual representations are a key ingredient of biology textbooks and it provides responses to the research question on the prevalence, distribution and trends of various categories of visuals in the textbooks. The key findings of the present study confirm the findings of Khine and Liu (2016) and Liu and Treagust (2013). The distribution of the visuals in the textbooks reflects their role in the teaching and learning of Biology. The significance of the visuals is that they act as a tool for conceptual change and conceptual clarity. This confirms the findings of Kindfield (1994). Out of the 4,143 visual analyzed, the TN biology book had the highest number of visuals followed by AP, IBDP, AS-A Level and CBSE books. On an average, IBDP had the highest number of visuals per chapter followed by AP, AS-A Level, TN and CBSE books. The mean of visual representations per page in each of the textbooks was found to be highest in IBDP followed by AS-A Level, TN, AP and CBSE. This proves the fact that visual representations can be used to convey large amounts of domain knowledge in a simplified manner.

Biology textbooks prescribed for the final years of schooling should give more emphasis on photomicrographs. The use of photomicrographs should not be exclusively restricted to the chapter "Cell Biology" and that relevant photomicrographs need to be distributed to complement the domain knowledge of different chapters. The authors of biology textbooks must always ensure that photomicrographs in biology textbooks are captioned with magnifications and are explanatory in function. Photomicrographs without scale of magnifications serve no purpose. The scale of magnification helps to understand and appreciate the microscopic nature of the different entities represented in the photomicrographs. Teachers must also highlight the importance of scale of magnification to the learners. Teachers must also provide conceptual clarity regarding magnification by providing a lot of examples related to calculations based on magnifications. Teachers must also encourage the learners to appreciate the realistic images of cells, cell organelles, tissues and microbes through the use of photomicrographs. With respect to photographs, authors of biology textbooks must ensure that photographs serve in explaining, illustrating and complementing biology concepts addressed by them and that photographs should not be used as mere space-filling or decorative objects. In this study, it is reported that the biology textbooks for AP, AS-A Level and IBDP have explanatory functions, whereas that of CBSE and TN Board have illustrative functions. The use of iconic diagrams (other than photographs and photomicrographs) in biology textbooks is mostly related to animal physiology, plant physiology, animal anatomy and plant anatomy. Authors must always ensure that iconic

diagrams are of standard size and quality. Biology textbooks at the secondary level use more schematic diagrams than at the primary level. Although schematic diagrams help to explore and interpret complex information of the domain knowledge in a simplified manner using symbols, lines and shapes, at the same time, it should be ensured that the schematic diagrams are not over-simplified representations as reported by Novick (2006). Teachers must also facilitate students in interpreting schematic diagrams using effective diagrammatic reading skills without losing the reality. The didactic advantages of schematic diagrams are well highlighted by Cwilewicz and Tomczak (2006). Teachers must also ensure that iconic diagrams and schematic diagrams are utilized well for the creation of mental models of complex and complicated domain knowledge. The use of graphs and charts in biology textbooks helps to understand concepts related to dependent and independent variables. Interpreting graphs and charts needs intellectual wisdom and teachers must ensure that such wisdom is provided to their learners. This is confirmed by the findings of Mevarech and Stern (1997). Learners should be encouraged to work on graphs and charts from science journals and authors of biology textbooks need to provide such visual representations. In this study, it is reported that science journal-based graphs and charts were found to be maximum in AP Biology Textbook of Openstax. The visuals under the categories D10C (Computer Generated Images), D10E (CryoEM Structural Images) and D10M (Molecular Visualization Software Images) find poorly represented in biology textbooks. The reason behind this is that these categories of visuals are found to be used exclusively to explain concepts pertaining to biochemistry, especially that of the structure of proteins and enzymes. In this study, it was reported that the visuals under the first two categories were found in IBDP and AS-A Level books, whereas the last category of visuals was found only in IBDP. Authors in future should make more use of such categories of images to explain concepts in domains other than biochemistry such as physiology and evolution.

Future studies related to visual representations can address the following limitations of the present study: (a) In addition to results obtained through qualitative and quantitative analysis of visual categories, opinions from teachers and students can be sought to review and explore the usage of visual representations. (b) In this study, visuals from biology textbooks of international, national and regional boards of higher secondary education in the Asian region were considered, and this was found to be exhaustive. Future studies can include visuals of textbooks of school boards in other countries. (c) Other methods of analysis of visual representations can be tried. (d) The sample size of this study was limited to five textbooks of nine volumes from five educational boards. The number of books can be increased in future studies.

7. Conclusions

The end product of teaching and learning processes in biology is conceptual change. The process where concepts and relationships between the concepts change over the course of an individual's (learner's) lifetime is called conceptual change. It means restructuring of one's existing knowledge and beliefs. Conceptual change in an individual depends on active engagement and prior knowledge of the learner. The study presented here considered visual representation as a constructive learning tool that facilitates the process of conceptual change in the learner. It is widely believed that a well designed and visual-friendly biology textbook will benefit students to avoid scientific misconceptions in biology.

The novel aspect of this study is the comparison of visual representation categories among the biology textbooks of five different educational boards, thereby providing insight to biology teachers, textbook developers and textbook evaluators on the method to be used in textbook analysis from the context of visual representations. The following are the significant contributions to the literature. First, the study has updated the typology on diagrams or visual representations of Hegarty et al. (1991), Leivas Pozzer and Roth (2003), and Novick (2006). Second, the empirical findings focusing on the distribution of different categories of visual representations within the different chapters across each of the five books have been provided. Lastly, the study also provides empirical findings on the trends in the usage of different categories of visuals across the biology textbooks of different educational boards.

Author details
Parthasarathy J[1]
E-mail: parthajagan007@gmail.com
ORCID ID: http://orcid.org/0000-0002-8108-735X
Premalatha T[2]
E-mail: premalatha@buc.edu.in
ORCID ID: http://orcid.org/0000-0003-0535-357X
[1] Department of Education, Bharathiar University, Coimbatore 641 046, India.
[2] Assistant Professor, Department of Education, Bharathiar University, Coimbatore 641046, India.

Ethical issues (Originality and plagiarism)
The authors of this study ensure that they have written entirely original works.

Ethical research
This submission conforms to the American Educational Research Association "Code of Ethics" on research.

Disclosure statement
No potential conflict of interest was reported by the author(s).

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Submission declaration and verification
The work described by the authors has not been published previously, and it is not under consideration for publication elsewhere. The authors approve the publication of this work. If accepted, it will *not* be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright holder.

Citation information
Cite this article as: Content analysis of visual representations in biology textbooks across selected educational boards from Asia, Parthasarathy J & Premalatha T, *Cogent Education* (2022), 9: 2057002.

References

Agrawal, R., Gollapudi, S., Kannan, A., & Kenthapadi, K. (2011). Identifying enrichment candidates in textbooks. *Proceedings of the 20th international conference companion on World wide web - WWW '11* Hyderabad, India. https://doi.org/10.1145/1963192.1963362

Carvalho, G. S., Tracana, R. B., Skujiene, G., & Turcinaviciene, J. (2011). Trends in environmental education images of textbooks from western and Eastern European countries and Non-European countries. *International Journal of Science Education*, *33*(18), 2587–2610. https://doi.org/10.1080/09500693.2011.556831

Cwilewicz, R., & Tomczak, L. (2006)Application of 3D computer simulation for marine engineers as a hazard prevention tool *Risk Analysis V: Simulation and Hazard Mitigation* . https://doi.org/10.2495/risk060291

Gagné, R. M. (1969). Reviews: Ausubel, David P. Educational psychology: A cognitive view. *American Educational Research Journal*, *6*(2), 287–290. New York: Holt, Rinehart & Winston, 1968. 685 + xviii pp. $8.95 https://doi.org/10.3102/00028312006002287

Giannantonio, C. M. (2008 Content Analysis: An Introduction to Its Methodology). . *Organizational Research Methods* 2 , (Thousand Oaks: Sage)), 392–394. https://doi.org/10.1177/1094428108324513

Hegarty, M., Carpenter, P. A., & Just, M. A. (1991). Diagrams in the comprehension of scientific texts. In R. Barr, M. L. Kamil, P. Mosenthal, & P. D. Pearson (Eds.), *Handbook of reading research* (Vol. 2, pp. 641–668). Longman.

Hurley, S. M., & Novick, L. R. (2010). Solving problems using matrix, network, and hierarchy diagrams: The consequences of violating construction conventions. *Quarterly Journal of Experimental Psychology*, *63*(2), 275–290. https://doi.org/10.1080/17470210902888908

Khine, M. S., & Liu, Y. (2016). Content analysis of the diagrammatic representations of primary science textbooks. *EURASIA Journal of Mathematics, Science and Technology Education*, *12*(8 1937–1951). https://doi.org/10.12973/eurasia.2016.1288a

Kindfield, A. C. (1994). Biology diagrams: Tools to think with. *Journal of the Learning Sciences*, *3*(1), 1–36. https://doi.org/10.1207/s15327809jls0301_1

Leivas Pozzer, L., & Roth, W. (2003). Prevalence, function, and structure of photographs in high school biology textbooks. *Journal of Research in Science Teaching*, *40*(10), 1089–1114. https://doi.org/10.1002/tea.10122

Liu, Y., & Treagust, D. F. (2013). Content analysis of diagrams in secondary school science textbooks. *Critical Analysis of Science Textbooks*, 287–300. https://doi.org/10.1007/978-94-007-4168-3_14

Mathai, S., & Ramadas, J. (2009). Visuals and visualisation of human body systems. *International Journal of Science Education*, *31*(3), 439–458. https://doi.org/10.1080/09500690802595821

Mevarech, Z. R., & Stern, E. (1997). Interaction between knowledge and contexts on understanding abstract mathematical concepts. *Journal of Experimental Child Psychology*, *65*(1), 68–95. https://doi.org/10.1006/jecp.1996.2352

Newton, L. D. (2003). The occurrence of analogies in elementary school science books. *Instructional Science*, *31*(6), 353–375. https://doi.org/10.1023/A:1025706410666

Novick, L. R. (2006). The importance of both diagrammatic conventions and domain-specific knowledge for diagram literacy in science: The hierarchy as an illustrative case Diagrams'06: Proceedings of the 4th international conference on Diagrammatic Representation and Inference June 2006. , 1–11. https://doi.org/10.1007/11783183_1

Piaget, J. (1964). Part I: Cognitive development in children: Piaget development and learning. *Journal of Research in Science Teaching*, *2*(3), 176–186. https://doi.org/10.1002/tea.3660020306

Slough, S. W., McTigue, E. M., Kim, S., & Jennings, S. K. (2010). Science textbooks' use of graphical representation: A descriptive analysis of four sixth grade science texts. *Reading Psychology*, *31*(3), 301–325. https://doi.org/10.1080/02702710903256502

Vinisha, K., & Ramadas, J. (2013). Visual representations of the water cycle in science textbooks. *Contemporary Education Dialogue*, *10*(1), 7–36. https://doi.org/10.1177/0973184912465157

Vygotsky, L. S. (1980). Biographical note on. *Mind in Society*, 15–16. https://doi.org/10.2307/j.ctvjf9vz4.5

© 2022 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

You are free to:
Share — copy and redistribute the material in any medium or format.
Adapt — remix, transform, and build upon the material for any purpose, even commercially.
The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms:
Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made.
You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
No additional restrictions

You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

Cogent Education **(ISSN: 2331-186X) is published by Cogent OA, part of Taylor & Francis Group.**

Publishing with Cogent OA ensures:

- Immediate, universal access to your article on publication
- High visibility and discoverability via the Cogent OA website as well as Taylor & Francis Online
- Download and citation statistics for your article
- Rapid online publication
- Input from, and dialog with, expert editors and editorial boards
- Retention of full copyright of your article
- Guaranteed legacy preservation of your article
- Discounts and waivers for authors in developing regions

Submit your manuscript to a Cogent OA journal at www.CogentOA.com