International Journal of Enhanced Research in Educational Development (IJERED)
ISSN: 2320-8708, Vol. 9 Issue 5, Sept-Oct, 2021, Impact Factor: 7.326

Misconceptions and Elements of Conceptual Change in Higher Secondary Biology Textbooks in relation to 'Cell Structure'

Parthasarathy J[1], Premalatha T[2]

[1]Research Scholar, Department of Education, Bharathiar University, Tamil Nadu, India
[2]Assistant Professor, Department of Education, Bharathiar University, Tamil Nadu, India

ABSTRACT

The major aim of the present study is to identify the gap between traditional and modern biology textbooks with respect to elements of conceptual change. Content analysis of the lesson 'Cell Structure' in five biology textbooks of Grades 11 and 12 across selected educational boards in Asia was carried out to identify elements of conceptual change (associated with Posner's Model of Conceptual Change) needed for the replacement of some common existing misconceptions in 'Cell Structure'. These four conditions or elements have been respectively termed as 'Dissatisfaction', 'Intelligibility', 'Plausibility' and 'Fruitfulness'. Biology textbooks of five different educational boards were analyzed for the presence of the above four elements of conceptual change needed for the replacement of some common existing misconceptions in 'Cell Structure' such as 'Resolution of Light Microscopes can be improved by Enhancing the Design of the Light Microscope', 'Dimensions of objects in the microscopic world can never be measured' and 'Exchange of organic molecules between the Cell and its environment is a function that depends on Cell Surface Area and not Cell Volume'. The results of the analysis indicate that the text presentation in biology textbooks of international boards are non-expository with refutational characteristics fostering conceptual understanding by 'reasoning and inquiry' whereas in biology textbooks of Indian educational boards it is expository, fostering conceptual understanding by 'memorization'.

Keywords: Cell Structure; Conceptual Change; Content analysis; Expository Text; Refutational Text

INTRODUCTION

Learning in science education primarily happens by conceptual change. Conceptual change can be defined as the restructuring of the existing knowledge. [1] have reviewed and discussed the development of conceptual change over the past three decades and stressed it as a powerful framework for improving science teaching and learning. Conceptual change is influenced by many factors such as culture and society [2, 3], emotions [4], epistemological beliefs [5], motivation [6], personal practices and beliefs [7] cognitive and developmental factors. Apart from these, textbooks also have an influence on conceptual change [8]. In this study, biology textbooks were analyzed in the light of conceptual change pertaining to the learning of concepts in the lesson 'Cell Structure'. The theoretical foundation behind this study is the Model of Conceptual Change proposed by [9]. According to this model, for conceptual change learning to happen, four conditions must be fulfilled. They are 1. The prior knowledge that learners possess must be identified as inadequate to solve a given problem, 2.The new knowledge must be understandable, 3. The new knowledge must be useful in solving the current problem and 4. The new knowledge must appear to be useful in solving future problems. These four conditions or elements have been respectively termed as 'Dissatisfaction', 'Intelligibility', 'Plausibility' and 'Fruitfulness'. In the present study, biology textbooks of five different educational boards were analyzed for the presence of the above four elements of conceptual change needed for the replacement of some common existing misconceptions in 'Cell Structure' such as 'Resolution of Light Microscopes can be improved by Enhancing the Design of the Light Microscope', 'Dimensions of objects in the microscopic world can never be measured' and 'Exchange of organic molecules between the Cell and its environment is a function that depends on Cell Surface Area and not Cell Volume'.

In the 'Biology Textbook for the Tamil Nadu Board of Higher Secondary Education (TN Board)', apart from content-overload due to the expository nature of the topics, there is a lack of clarifications on misconceptions in large areas of the lesson. Some of the examples that clearly highlight misconceptions are as follows: Even before the throwing clarity on the concepts of protoplasm and cytoplasm, 'The Protoplasm Theory' and 'Physical Properties of Protoplasm'

has been discussed under the section 'Cell Theory'. The concept of Cytoplasm under the section 'Plant and Animal Cell' is introduced only after the discussion of Protoplasm, Cell Wall, Cell Membrane, Fluid-Mosaic Model, Cell Transport, Signal Transduction (in that order).The points of misconception here are with regard to the description of cytoplasm and protoplasm and about the electrical conductivities of protoplasm and cytoplasm. In the textbook, the cytoplasm is described as the "....semi-fluid gelatinous substance that fills the cell" and protoplasm is also described as the ".....living content of the cell that is surrounded by plasma membrane'. These two statements do not help in differentiating the protoplasm and cytoplasm thereby resulting in misconceptions. Likewise, scientific reasons have not provided for the scientific truths such as: ".....the cytoplasm is a very good conductor of electricity and the protoplasm is neither a good conductor nor bad conductor of electricity". Here the misconceptions arise because if the cytoplasm is a part of protoplasm then how do both cytoplasm and protoplasm have different electrical conductivities?

Table 1: Descriptions 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
1. International Baccalaureate (IB) (previously International Baccalaureate Organization – IBO)	16-19 Years	Biology Course Companion	Andrew Allot and David Mindorff	Oxford University Press, Oxford, United Kingdom	One	719
2. Cambridge Assessment International Examination (CAIE) (previously Cambridge International Examinations – CIE)	16-19 Years	Biology Course Book	Mary Jones, Richard Fosbery, Jennifer Gregory, Dennis Taylor	Cambridge University Press, United Kingdom	One	696
3. 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
4. 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
5. 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
						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

METHODOLOGY

A. Sample

The population for the present study includes biology textbooks of different educational boards prescribed for the students of age group between 16 and 19 years. The sample for the study includes five biology textbooks and the descriptions about these textbooks are presented in Table 1.The reason behind choosing these textbooks is their wide scale usage by students and teachers in the Indian subcontinent as well as in many Asian countries.

B. Analysis Procedure

Content analysis of the manifest content of the lesson 'Cell Structure' involved a thorough and systematic reading of the lesson 'Cell Structure' in order to identify elements of conceptual change namely dissatisfaction, intelligibility, plausibility, and fruitfulness with respect to replacement of certain common misconceptions [10]. Each element of conceptual change in the Posner's (1982) Model of Conceptual Change was operationalized for content analysis as given below

Dissatisfaction
Dissatisfaction is analyzed in terms of statements showing inadequacy or delimits or disadvantages. Here the author exposes the learners to phenomena that the current conceptions cannot explain.

Intelligibility
Intelligibility is measured by determining the number of pages required to present the theory or the concept. In the light of Posner's Model, intelligibility refers to the learner's ability to represent an idea [9]. In content analysis of textbook, this could be taken as the author's description of a theory or a concept to the learner. It should be understood that when greater the number of pages is needed to describe a theory or concept, it becomes more difficult to construct a representation of the theory or the concept.

Plausibility
Plausibility is analyzed in terms of the statements which provide evidences that the new conception helps to solve problems the old concepts could not.

Fruitfulness
Fruitfulness is analyzed in terms of the examples related to the additional application of the new conception.

RESULTS AND ANALYSIS

Table 2 shows some of the common misconceptions in 'Cell Structure' that have been clarified by the five biology textbooks. Of the total 29 misconceptions considered, the AP biology textbook clarified 75.8%, the AS-A Level clarified 37.9%, the IBDP and TN textbooks clarified 24.1% each and lastly the CBSE textbook clarified only13.8% misconceptions. Out of the five textbooks analyzed, the elements of conceptual change needed for the replacement of the misconceptions 'Resolution of Light Microscopes can be improved by Enhancing the Design of the Light Microscope' was reported in two textbooks (IBDP and AS-A Level), that for the replacement of the misconception 'Dimensions of objects in the microscopic world can never be measured' was reported only in one textbook (AS-A Level) and for the misconception 'Exchange of organic molecules between the Cell and its environment is a function that depends on Cell Surface Area and not Cell Volume' was also reported in one textbook (AP Board) only.

Table 2: Common Misconceptions in Learners clarified in the Five Biology Textbooks

Common Misconceptions in Learners	Correct Concepts	Page Numbers showing the Correct Concepts				
		Book 1	Book 2	Book 3	Book 4	Book 5
Cell Theory is applicable to all cells.	Cell Theory has its exceptions. Cell theory cannot be applied to striated muscle fibers, coenocytic hyphae, one cell algae *Acetabularia* and viruses.	174	-	2-3	-	-
All cells are capable of cell division.	Majority of the cells undergo cell division, except certain cells like nerve cells, heart muscle cells and fat cells.	-	-	-	-	-
All cells are microscopic.	Majority of the cells are microscopic except egg cells of birds	-	126	-		154
All plant cells do photosynthesis.	Plant cells with chloroplasts alone do photosynthesis.	-	134	-	6	172
All cells have lysosomes.	Lysosomes are present in animal cells and absent in plant cells .	189	-	-	16	164, 172
All cells have centrosomes.	Centrosomes are present in animal cells and absent in plant cells.	-	138		18	163-164
All eukaryotic cells have a nucleus.	Majority of the eukaryotic cells have nucleus. Matured RBC, Xylem Vessels do not have nucleus.	-	-	-	-	-
All cells are spherical in shape.	Not all cells are spherical in shape but most tend to approximate a sphere.	-	-	-	-	154-155
Animal cells without centrosomes do not divide.	Animal cells divide even when centrioles are removed.	-	-	-	-	164
Bigger the size of the cell greater is its efficiency.	Bigger sized cells have smaller cell surface area to volume ratio and therefore less efficient.	-	-	9	-	154-155
Cell division and cell differentiation are the same.	Cell division is the process by which a parental cell divides into two or more daughter cells whereas differentiation refers to the development of cells in different ways to carry out specific functions.	-	-	11	-	-
Cells in a tissue are fused with one another.	Cells in a tissue are held by extracellular matrix called proteoglycans.	-	-	-	-	179
Cells grow to be efficient.	As cells grow they become less efficient whereas cells divide to be efficient.	-	-	-	-	155
Cytoplasm Is the liquid part of the cell.	Cytoplasm is a semi-fluid gelatinous substance found in the cell.	184	-	-	5	160-161

Cytoplasm is the transport medium within the cell	Cytoskeleton in cells helps in transportation within the cells.	-	-	-	-	173-174
Cytoplasm of one cell is not continuous with the adjacent cell.	Cytoplasm of one cell is continuous with its neighboring cell with the help of plasmodesmata.	181	-	-	5	179-180
All things microscopic are about the same size.	All things microscopic are not uniform in size.	176	-	-	6	154
Nucleus is always found at the centre of the cell	In plant cells nucleus is found away from the center whereas the in animal cells nucleus is found at the center of the cell.	-	-	-	-	-
Nucleoid is the nucleus of prokaryotes.	The genetic material of a bacterial cell is found distributed in a region called nucleoid.	176	-	18-19	-	152-153
Nucleus and other cell organelles float in cytoplasm.	Nucleus and other cell organelles are anchored in the cell cytoplasm with the help of cytoskeleton structures.	-	136	-	17-18	173
Chromatin and Chromosomes are one and the same.	Chromatin is a thread-like structure which gets condensed to form chromosome prior to cell division.	192	-	21	15	161
Peroxisomes and glyoxysomes are different.	Glyoxysome is a type of perioxisome.	-	-	-	-	163
pH of lysosomes and pH of cytoplasm are identical.	pH of lysosomes is acidic when compared with the pH of the cytoplasm.	-	-	-	-	172
Vesicles and Vacuoles are the same.	Vesicles are smaller than vacuoles. Vesicles are capable of adhering to the cell membrane whereas vacuoles do not.	-	-	22	5	163
Vesicles swim in the cytoplasm.	Vesicles move along the cytoskeleton of the cell.	-	-	-	15	173
Mitochondrion creates energy for the cell to function.	Mitochondrion releases energy stored in bio-molecules. Energy can neither be created nor be destroyed but can be transformed from one form to another.	-	-	-	-	163
WBC show amoeboid movement due to its cell membrane.	Microfilaments in WBCs depolymerise and repolymerise quickly, so that its shape changes and helps in movement.	-	-	-	-	173
Greater the magnification, greater is the resolution of a microscope.	Resolution can never be improved with increased magnification.	-	-	-	10	-
Resolution and wavelength of light are independent.	Shorter the wavelength of light used, greater the resolution of the microscope.	-	-	17	11	-
Total Number of Correct Clarifications Reported in the Textbooks (Percentage)		**7 (24.1%)**	**4 (13.8%)**	**7 (24.1%)**	**12 (37.9%)**	**22 (75.8%)**

Key: Book 1: 'Biology Textbook for the Tamil Nadu Board of Higher Secondary Education (TN Board) Grades 11 and 12', Book 2: 'Biology Textbook for Central Board of Secondary Education (CBSE) Grades 11 and 12', Book 3: 'Biology Course Companion for International Baccalaureate Diploma Program (IBDP)', Book 4: 'Biology Course Book for Advanced Subsidiary and Advanced Level (AS-A Level)' and Book 5: 'Biology for Advanced Placements (AP Board)'.

Table 3: Elements of conceptual change related to the misconception 'Resolution of Light Microscopes can be never be improved by Enhancing the Design of the Light Microscope'

Textbook	Element			
	Dissatisfaction[1]	**Intelligibility[2]**	**Plausibility[3]**	**Fruitfulness[4]**
Book 1	None	Electron Microscope, Components and Types of Microscopes. (Pg: 171-174).	None.	None
Book 2	None	None	None	None
Book 3	Light Microscopes have limited resolution (Pg: 17).	Developments in scientific research follow improvements in apparatus: the invention of electron microscopes. (Pg: 17-18).	Drawing the ultrastructure of prokaryotic cells and eukaryotic cells based on electron micrographs. (Pg: 19, Pg: 21-23). Understanding the electron micrograph of liver cell and its cell organelles. (Pg: 23).	Intepreting the electron micrographs to identify organelles and deduce the function of specialized cells (Pg: 25).
Book 4	Light Microscopes: microscopists became frustrated because they realized that no matter how much the ever the design of the light microscopes got improved, there was a limit to	Magnification (Pg: 6), Resolution (Pg:10), Electromagnetic Spectrum (Pg: 11), Electron Microscopy – Transmission Electron Microscope and Scanning Electron Microscope,	Cell Organelles like Ribosomes, can be viewed using electron microscopes. (Pg: 15).	Ultrastructure of an Animal Cell. (Pg: 13)

	how much could ever be seen using light. (Pg: 6).	Viewing specimens with Electron Microscope (Pg: 11-13).		
Book 5	None	Electron Microscopes. Transmission and Scanning Electron Microscopes. (Pg:149).	None	None

Table 4: Elements of conceptual change related to the misconception 'Dimensions of objects in the microscopic world can never be measured'

Textbook	Element			
	Dissatisfaction	Intelligibility	Plausibility	Fruitfulness
Book 1	None	Microscopic Measurements: Ocular Micrometer, Stage Micrometer.	None	None
Book 2	None	None	None	None
Book 3	None	None	None	None
Book 4	Objects in the microscopic world, can be measured using very small units of measurement. These are unfamiliar to people. In cell studies: μ is the Greek letter mu; is the units of measurement. (Pg 6).	Measuring Cells: Eye-piece Graticule and Stage Micrometer. Calculating the magnification of a photograph or image using the formula $M = I/A$. Where M is magnification, I is Image Size and A is Actual Size. (Pg: 7-8).	Numerical Problem related to application of the magnification formula. Calculating magnification from a scale bar. Worked out example on Calculating the real size of an object from its Magnification (Pg: 8-9)	Exercise numerical Problem on calculation of actual size. (Pg: 24, Question 9).
Book 5	None	None	None	None

Table 5: Elements of conceptual change related to the misconception 'Exchange of organic molecules between the Cell and its environment is a function that depends on Cell Surface Area and not Cell Volume'

Textbook	Element			
	Dissatisfaction	Intelligibility	Plausibility	Fruitfulness
Book 1	None	None	None	None
Book 2	None	None	None	None
Book 3	Limitations on Cell Size (Pg: 9)	Cell Volume, Surface Area, Surface Area to Volume Ratio and its advantages. (Pg 9)	None	None
Book 4	None	None	None	None
Book 5	Small size, in general, is necessary for all cells, whether prokaryotic or eukaryotic. The small size of prokaryotes allows ions and organic molecules that enter them to quickly diffuse to other parts of the cell. This is not the case in eukaryotic cells, which have developed different structural adaptations to enhance intracellular transport. (Pg: 154).	Notice that as a cell increases in size, its surface area-to-volume ratio decreases. When there is insufficient surface area to support a cell's increasing volume, a cell will either divide or die. The cell on the left has a volume of 1 mm^3 and a surface area of 6 mm^2, with a surface area-to-volume ratio of 6 to 1, whereas the cell on the right has a volume of 8 mm^3 and a surface area of 24 mm^2, with a surface area-to-volume ratio of 3 to 1 (Pg: 155).	A worked out numerical problem providing quantitative justification them significance of cell surface area to volume ratio with respect efficiency of exchange of nutrients and wastes with a cell's environment. (Pg: 156).	A task that seeks the learner to draw annotated diagram to explain how approximately 300 million alveoli in a human lung increases surface area for gas exchange to the size of a tennis court. (Pg: 156).

Key: Book 1: 'Biology Textbook for the Tamil Nadu Board of Higher Secondary Education (TN Board) Grades 11 and 12', Book 2: 'Biology Textbook for Central Board of Secondary Education (CBSE) Grades 11 and 12', Book 3: 'Biology Course Companion for International Baccalaureate Diploma Program (IBDP)', Book 4: 'Biology Course Book for Advanced Subsidiary and Advanced Level (AS-A Level)' and Book 5: 'Biology for Advanced Placements (AP Board)'. [1]Dissatisfaction—the author exposes the learners to phenomena that the current conceptions cannot explain; [2]Intelligibility—the author provides description about the new conception; [3]Plausibility—The author provides evidences that the new conception helps to solve problems the old concepts could not; and [4]Fruitfulness—the author provides examples about the additional application of the new conception.

DISCUSSION

Owing to the fact that biology is a conceptual science, many learners find difficulties in understanding biological concepts. This has led students to memorize biological concepts rather than using techniques of conceptual learning [11]. Learners adopt procedural learning when they are unable to link a new knowledge with their pre-existing knowledge [12]. This leads to the generation of misconceptions. The cause for misconception can be insufficiency of prior knowledge in the learner, insufficiency of content knowledge in the teacher, textbooks, use of daily life language instead of scientific language and lastly influence of cultural factors [13-17]. The present study reports that out of the 29 misconceptions considered, 75.8% of them have been clarified and refuted by 'Biology for Advanced Placements (AP Board)' whereas 37.9% by 'Biology Course Book for Advanced Subsidiary and Advanced Level (AS-A Level)'.This reveals that text presentation in these textbooks is refutational in characteristics. Further, the present study also found that out of the five textbooks analyzed, the elements of conceptual change needed for the replacement of the three common misconceptions (while learning 'Cell Structure') namely 'Resolution of Light Microscopes can be improved by Enhancing the Design of the Light Microscope', 'Dimensions of objects in the microscopic world can never be measured' and 'Exchange of organic molecules between the Cell and its environment is a function that depends on Cell Surface Area and not Cell Volume' are reported only in the three biology textbooks of the international boards which refuted single idea misconceptions rather than complex ideas. The effectiveness of text presentation also depends on the nature of misconceptions being refuted. In such a text presentation, less change would be required to accommodate the new information. Similar findings have also been reported by [18].

CONCLUSION

From the perspective of conceptual change, all the three biology textbooks of international boards reveal elements of conceptual change with respect to misconceptions and these evidences highlight the refutational characteristics of these textbooks. The present study clearly substantiates the fact that biology textbooks from India need serious revision and improvement.The study recommends that in order to enhance the learners' analytical and reasoning ability in biology, the curricular objectives of educational boards from India should be revised and aligned with the curricular objectives of international educational boards.

REFERENCES

[1]. Duit, R. and Treagust, D.F. (2003) Conceptual Change: A Powerful Framework for Improving Science Teaching and Learning. International Journal of Science Education, 25, 671-688. http://dx.doi.org/10.1080/09500690305016

[2]. Moje, E. B., & Shepardson, D. P. (2013). Social interactions and children's changing understanding of electric circuits. Perspectives on Conceptual Change, 31-40. https://doi.org/10.4324/9781315045108-10

[3]. Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. Learning and Instruction, 4(1), 45-69. https://doi.org/10.1016/0959-4752(94)90018-3

[4]. Gregoire, M. (2003). Is It a Challenge or a Threat? A Dual-Process Model of Teachers' Cognition and Appraisal Processes During Conceptual Change. Educational Psychology Review, 15(2), 147-179. https://doi.org/10.1023/a:1023477131081

[5]. Windschitl, Mark. (1997, July). The Pedagogical, Cultural, and Political Challenges of Creating a Constructivist Classroom [Paper presentation]. International Congress on Personal Construct Psychology (12th, Seattle, WA, July 9-11, 1997).

[6]. Pintrich, P. R., Smith, D. A., Garcia, T., & Mckeachie, W. J. (1993). Reliability and predictive validity of the motivated strategies for learning questionnaire (Mslq). Educational and Psychological Measurement, 53(3), 801-813. https://doi.org/10.1177/0013164493053003024

[7]. Chi, M. T. (2009). Active-constructive-Interactive: A conceptual framework for differentiating learning activities. Topics in Mikkilä-Erdmann, M. (2002). Science learning through text: The effect of text design and text comprehension skills on conceptual change. Reconsidering Conceptual Change: Issues in Theory and Practice, 337-353. https://doi.org/10.1007/0-306-47637-1_17

[8]. Cognitive Science, 1(1), 73-105. https://doi.org/10.1111/j.1756-8765.2008.01005.x

[9]. Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66, 211-227.* , *66*, 211-227. https://doi.org/10.1002/sce.3730660207

[10]. Shiland, T. W. (1997). Quantum mechanics and conceptual change in high school chemistry textbooks. *Journal of Research in Science Teaching*, *34*(5), 535-545. https://doi.org/10.1002/(sici)1098-2736(199705)34:5<535::aid-tea7>3.0.co;2-r

[11]. Özcan, Ö. (2000). The levels of students' understanding of basic concepts in reproduction and inheritance in the living things unit at 8th grade. *Unpublished Master Thesis, the Graduate School of Natural and Applied Sciences, Karadeniz Technical University*, Trabzon.

[12]. Kahveci, A. (2009). Quantitative Analysis of Science and Chemistry Textbooks for Indicators of Reform: A complementary perspective. International Journal of Science Education, 32(11), 1495-1519. https://doi.org/10.1080/09500690903127649

[13]. Aşçı et al., 2001 Z. Aşçı, Ş. Özkan, C. Tekkaya. (2001). Students' misconceptions about respiration. *Egitim ve Bilim Dergisi*, *26*(120), 29-36.

[14]. Goh, N. K., Khoo, L. E., & Chia, L. S. (1993). Some misconceptions in chemistry: A cross cultural comparison and implications for teaching. *Australian Science Teachers Journal*, *39*(3), 65-68.https://www.jstor.org/sTable/40188778

[15]. Storey, R. D. (1991). Textbook errors and misconceptions in Biology: Cell metabolism. *The American Biology Teacher*, *53*, 339–343.https://doi.org/10.2307/4449321

[16]. Harrison, A. G. (1998). Modeling science lessons: Are there better ways to learn with models?. *School Science and Mathematics*, *98*(8), 420-429.https://doi.org/10.1111/j.1949-8594.1998.tb17434.x

[17]. Lubben, F., Netshisuaulu, T. & Campell, B. (1999). Students' use of cultural metaphors and their scientific understandings related to heating. *Science Education*, *83*, 761-774.https://doi.org/10.1002/(SICI)1098-237X(199911)83:6<761::AID-SCE7>3.0.CO;2-O

[18]. Chi, M.T.H. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In *In S. Vosniadou (Ed.), International handbook of research on conceptual change* (pp. 61-82). New York, NY: Routledge.