

Content Analysis of Science Textbooks on the Misconceptions of Central Dogma of Molecular Biology

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ABSTRACT

The study aimed to examine the representations of the Central Dogma concepts in Science textbooks and analyse the potential contributions to students' misconceptions about the concept. The convergent parallel design was employed and utilized purposive sampling to determine the study participants. Science textbooks were also collected and analysed using document analysis, while the free word association test was employed to determine the teachers' perception of the concepts related to Central Dogma. Based on the findings, the study showed that the features of the textbooks like definition, figures, analogy, and assessment influence the learning of the learners, and even science teachers have misconceptions on the four concepts, namely: duplication, transcription, translation, and protein that related to the central dogma.

Keywords

Central Dogma, Science Education, Science Textbooks, Word Association Test, Science Teachers, Teaching Science

Introduction

Central Dogma is one the important topics and many students do not appreciate the significance of the central dogma (Khodor, Halme, & Walker, 2004). It was also pointed out that the high school curricula do not provide adequate scaffolding for students to deeply learn central dogma concepts (Lewis, Leach, & Wood-Robinson, 2000; Shaw, Van Horne, Zhang, & Boughman, 2008). Studies also show that various problems have met in teaching central dogma, like the explanation of canonical model of DNA to RNA to protein (Wright & Fisk, 2014), difficulty of the topics (Lewis & Wood-Robinson, 2000), concepts are at molecular level (Kozma & Russell, 2005), vagueness and imprecise language (Rector, Nehm, & Pearl, 2013), and poor in understanding the concepts (Chattopadhyay, 2005). Therefore, teaching the central dogma and its concepts posed a great challenge to the science teacher.

However, teachers applied different teaching strategies and approaches to teaching the central dogma concepts to the students. Some of these were the application of metacognitive inquiry activities (Chang, Lee, & Wen, 2020), contextualization (Picardal & Pano, 2018), analogy role-play activity (Takemura & Kurabayashi, 2014), physical models (Newman, Stefkovich, Clasen, Franzen, & Wright, 2018), group work paper model (Altıparmak & Nakiboglu Tezer, 2009), and epigenetics (Esser-Drits, Malone, Barber, & Stark, 2014). These strategies and approaches give positive results to the students and teachers during the teaching-learning process.

Word association, also known as associative experiment (Kostova & Radoynovska, 2010) is a test,

consisting of a list of words, administered to the respondent, who has to answer to each word by writing as many words that is related to the key concept that come to his or her mind. The concept (intellectual) map is a "nonlinear diagrammatic representation of meaningful relationships between concepts" (Giuliodori, Lujan, & Dicarlo, 2007), a mental model, a schematic representation, which is a hierarchical structure from interconnected words, ideas, problems, solutions, arranged around a key word in radial circles (Buzan & Buzan, 1996).

One of the learning materials that are commonly utilized by the teachers and students in the textbooks. Textbooks have a positive impact to the students because it improves the student's understanding on science concepts (Kartikasari, Roemintoyo, & Yamtinah, 2018), availability of content, organization, setting out of learning task (Schmidt, McKnight, & Raizen, 2002), and the congruity of content and aim (Chiappetta, Fillman, & Sethna, 1991). But textbooks have also glitches like other learning materials. Various studies pointed out that textbooks are merely focusing on the descriptions of facts (Smolkin, McTigue, & Yeh, 2011), produced by the non-experts and generally for commercial purposes (Gokce, 2009), and misconceptions (King, 2010). Thus, for the textbook to function as a useful instructional guide, its content must not only be suited to the interest and abilities of learner but rather, it must be acceptable in light of the current curriculum content standard point-of-view and avoid misconceptions.

Objectives of the Study

The study aimed to examine the representations of the Central Dogma concepts in Science textbooks and analysing them to reveal their potential contributions to students' misconceptions about the concept.

1. How are the concepts of Central Dogma presented in secondary high school Science textbooks in terms of: (a) definitions, (b) figures, and (c) analogies
2. How are the Central Dogma concepts present in local and foreign textbooks in terms of assessment activities?
3. How do these concepts presented in textbooks perceived by the teachers using word association test?
4. Is the demographic profile of the participants related to their perception of concepts?

Methods

The study utilized convergent parallel design to gain an in-depth understanding of the study. This method was used to gather qualitative data and quantitative elements in the same phase of the research process, weighs the method equally, but analysed the two elements independently, and interpreted the results together (Creswell & Plano, 2011). Textbooks were grouped into two as local and foreign categories. Local textbooks were textbooks written by local authors and published within the country. While foreign textbooks were textbooks written by foreign authors and published outside of the Philippines. All textbooks published and copyrighted from 2000-2020 and utilized by the science teachers during the teaching-learning process were part of the study. On the other hand, in determining the science teachers, purposive sampling were employed. The teacher must be a science teacher in junior or senior high school, utilized science textbooks in teaching or as reference and taught biological science subjects.

Data Analysis

In analysing the data, document analysis was used in the textbooks and free word association test for the teachers. The researchers compare the textbooks in terms of how it defines, show figures, and use analogy the four concept, namely; replication, transcription, translation and protein and the format of its assessment. Similarities and differences were noted and discuss and supported were noted and discuss and supported with related literature to support the claim of the study. While in free word association test, the teachers were given piece of paper and have a concept word written. The Science teachers handling Biology were presented with four key concepts in Central Dogma of Molecular Biology. These four key concepts, namely: replication, transcription, translation and protein were validated by science teachers that related to the main topic Central Dogma. Teachers were requested to write down the word/s each key concept evoked within 30 seconds. Their replies were matched with the key concepts and converted into frequency table and concept maps that represent the cognitive structures of the Science-Teachers handling Biology. The first part is constructed by recording the key concepts and the answers. In the concept map, all

the parts were constructed by determining all the answers given by the prospective teachers for the key concepts.

After an investigation of these four key concepts of the Central Dogma of Molecular Biology and consultation with four Doctoral students, the researchers decided on the concepts of replication, transcription, translation and protein as potential sources of misconception. Prior to administration, the researchers provided the necessary instructions, explanations and examples to the participants. Consulting relevant past studies, the researchers chose to allocate a 30-second period for each key concept (Bahar and Ozatli, 2003; Cardak, 2009, Ercan, Taşdere and Ercan, 2010). The Science teachers handling Biology were requested to write the words that the given key concept evoked on the page allocated for the respective concept in order of importance within 30 seconds. The detailed frequency table was constructed by the number of times the replies for the key concepts were iterated. The Detailed Frequency Table was used in the construction of the concepts maps. In the Cutoff Point Method, the total numbers of words given in reply to the key concepts are grouped by specific intervals and grouping intervals are used as cutoff points. The demo-graphic profile of the science teacher were also gathered to correlate it to their perceptions to the concepts of central dogma. Chi-square was used to establish the relationship of the variables.

Results and Discussion

The concepts of central dogma presented in secondary high school science textbooks varies in different ways.

Table 1 presents the manner how the local textbooks define the four concepts related to the Central Dogma.

Table 1. Local Textbooks Utilized by Science Teachers

Content	Definition	Source
Replication	A process of making two identical copies of DNA.	Acosta, et al., (2015). <i>Science 10 Learner's Material & Teacher's Guide 1st Edition</i>
	DNA replication is the careful reproduction of DNA molecules in a cell.	Evangelista, Luisito T. (2018). <i>General Biology 2 for Senior High School</i>
Transcription	The process in which the sequence of nucleotides in DNA directs the order of nucleotides in messenger RNA.	Acosta, et al., (2015) <i>Science 10 Learner's Material & Teacher's Guide 1st Edition</i>
	Transcription is the first of the three steps in protein synthesis.	Evangelista, Luisito T. (2018). <i>General Biology 2 for Senior High School</i>
	Transcription process produces mRNA from DNA.	Capco & Yang (2010). <i>You and the Natural World-</i>

		<i>Biology 3rd Edition</i>
Translation	The process of converting the information in messenger RNA into a sequence of amino acids that make a protein.	Acosta, et al., (2015). <i>Science 10 Learner's Material & Teacher's Guide 1st Edition</i>
	The translation of mRNA codons to amino acids forms polypeptides.	Evangelist, Luisito T. (2018). <i>General Biology 2 for Senior High School</i>
	Translation is the process of assembling protein molecules from the information encoded in the mRNA.	Capco & Yang (2010). <i>You and the Natural World- Biology 3rd Edition</i>
Protein	Proteins such as enzymes mostly amino acids chained together in a certain order.	Acosta, et al., (2015). <i>Science 10 Learner's Material & Teacher's Guide 1st Edition</i>
	Protein is the end product of DNA translation and is the most abundant molecule in a living organism.	Evangelista, Luisito T. (2018). <i>General Biology 2 for Senior High School</i>
	Protein is a structure of amino acid from short chains of peptides.	Capco & Yang (2010). <i>You and the Natural World- Biology 3rd Edition</i>

On the other hand, Table 2 presents how the foreign textbooks define the four concepts.

Table 2. Foreign Textbooks Utilized by Science Teachers

Content	Definition	Source
Replication	Several principles apply to all (or most) DNA replication: (1) Double-stranded DNA replicates in a semi-conservative manner. (2) DNA replication in <i>E. coli</i> (and in other organisms) is at least semi-discontinuous.	Weaver, Robert F. (2008). <i>Molecular Biology, Fifth Edition, McGraw Hill, New York, NY.</i>
	Each DNA strand is a template for a new strand. Each new DNA molecule contains one strand from the old DNA molecule and one newly synthesized strand. Because half of the old molecule is conserved in the new	Miller & Harley (2016). <i>Zoology 10th Edition, McGraw Hill Education</i>

	molecule. DNA replication is said to be semiconservative.	
	The replication of a chromosome begins at particular sites called origins of replication short stretches of DNA having a specific sequence of nucleotides.	Breece, et al., (2014). <i>Campbell Biology 10th Edition</i>
	DNA replication begins with one DNA double helix and ends with two DNA double helices.	Starr, Evens, & Starr (2018). <i>Biology. Today and Tomorrow Biology for Non-Science Major</i>
Transcription	The first step of the Central Dogma is the transfer of information from DNA to RNA, which occurs when an mRNA copy of the gene is produced. Like all classes of RNA, mRNA is formed on a DNA template. Because the DNA sequence in the gene is transcribed into an RNA sequence, this stage is called transcription .	Weaver, Robert F. (2008). <i>Molecular Biology, Fifth Edition, McGraw Hill, New York, NY.</i>
	It involves numerous enzymes that unwind a region of a DNA molecule, initiate and end mRNA synthesis, and modify the mRNA after transcription is complete.	Miller & Harley (2016). <i>Zoology 10th Edition, McGraw Hill Education</i>
	Transcription is the synthesis of RNA using information in the DNA.	Breece, et al., (2014). <i>Campbell Biology 10th Edition</i>
	Transcription is a process in which enzymes use the DNA sequence of a gene as a template to assemble a strand of RNA. Transcription makes a copy of a gene.	Starr, Evers & Starr (2018). <i>Biology. Today and Tomorrow Biology for Non-Science Major</i>
Translation	The second step of the Central Dogma is the transfer of information from RNA to protein, which occurs when the information contained in the mRNA transcript is used to direct the sequence of amino acids	Weaver, Robert F. (2008). <i>Molecular Biology, Fifth Edition, McGraw Hill, New York, NY</i>

during the synthesis of polypeptides by ribosomes. This process is called **translation** because the nucleotide sequence of the mRNA transcript is translated into an amino acid sequence in the polypeptide.

A protein synthesis at the ribosomes in the cytoplasm, based on the genetic information in the transcribed mRNA. Miller & Harley (2016). *Zoology 10th Edition, McGraw Hill Education*

Translation is the synthesis of RNA using information in the DNA. Breece, et al., (2014). *Campbell Biology 10th Edition*

Translation is a process by which a polypeptide chain is assembled from amino acids in the order specified by an mRNA. Starr, Evers & Starr (2018). *Biology: Today and Tomorrow Biology for Non-Science Major*

Protein Produced on the ribosomes on the surface of the rough endoplasmic reticulum. Miller & Harley (2016). *Zoology 10th Edition, McGraw Hill Education*

A **protein** is a biologically functional molecule made up of one or more polypeptide, each folded and coiled into a specific three dimensional structure. Breece et al., (2014). *Campbell Biology 10th Edition*

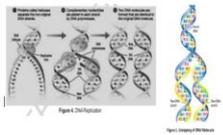
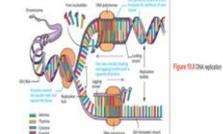
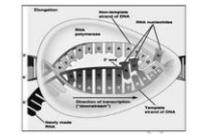
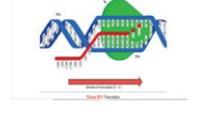
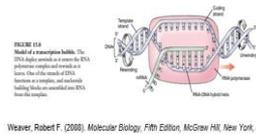
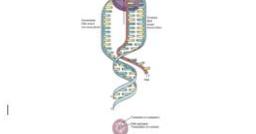
Organic compound that consists of one or more chain amino acid. Starr, Evers & Starr (2018). *Biology: Today and Tomorrow Biology for Non-Science Major*

Foreign textbooks commonly defined science concepts in the extracted definition than local textbooks. Local textbooks define the concepts in a short and brief statement. While the foreign textbook, define the concepts in a more elaborated and sometimes introduce first the steps or situations before the concept. According to Bayda & Sutliff (2020), students should be taught extracted definitions, to help them create concept images that relates definitions to the real world.

While in presenting figures related to the two concepts of Central Dogma of local and foreign textbooks,

Table 3 presents the figures showing the similarities and differences.

Table 3. Local and Foreign Science Textbooks showing the Figures of the Concepts of Central Dogma

Concept	Local Textbook	Foreign Textbook
Replication	 <p>Acosta, et al. (2015). Science 10 Learner's Material & Teacher's Guide 1st Edition</p>  <p>Evangelista, Lulick, T. (2016). General Biology 2 for Senior High School</p>	 <p>Acosta, et al. (2015). Science 10 Learner's Material & Teacher's Guide 1st Edition</p>  <p>Evangelista, Lulick, T. (2016). General Biology 2 for Senior High School</p>
Transcription	 <p>Acosta, et al. (2015). Science 10 Learner's Material & Teacher's Guide 1st Edition</p> 	 <p>Weaver, Robert F. (2008). Molecular Biology, Fifth Edition, McGraw Hill, New York, NY.</p>  <p>Miller & Harley (2016). Zoology 10th Edition, McGraw Hill Education</p>

Foreign textbooks contain descriptions or explanations about the figure presented than local textbooks. In local textbooks, the label of the figure is present and the name of the picture and label were provided but details were lacking. The foreign textbooks, write the figure and elaborated discussion of the picture or diagram. There were also arrows which shows the direction of the flow or process and details were provided. Mayer & Gallini (1990) posited that illustration or diagrams are effective when both the text and illustrations are “appropriate” for the task. And carefully constructed text illustrations generally enhance learner’s performance (Carney & Levin , 2002).

In Table 4, both local and foreign science textbooks used the analogy in discussing the topics of the central dogma. Analogies like car-making and construction working were found in local textbooks. Furthermore, machine, one-room workshop and book were some analogies found in foreign textbooks. Simanek (2010) stressed out that science students have to be exposed to analogical reasoning to understand the nature and common arguments of science. Curtis and Reigeluth (1984) stated also that analogies are generally believed to aid learning of unfamiliar concepts and

associated with transcription; it is an existence of misconception is the central dogma of biology.

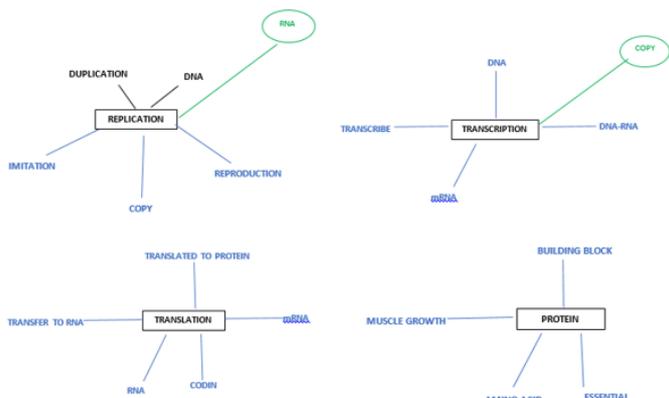


Figure 2. Concept Map with a Cut-off Interval of 3-5

In the cut-off interval of 1-2, the red line and red words (Figure 3) are considered the least associated words in the key concepts. Figure 3 shows an increase in the number of associations for the concepts of replication, transcription, translation and protein. However, replies for the key concepts of DNA in translation is a misconception. The highest rank of associated word for replication is duplication, for transcription is DNA, for translation are transfer of RNA and coding and protein are building blocks, muscle growth, amino acid and essential food. In addition, RNA and DNA are associated with the key concept of protein and DNA is associated with translation; it is also a misconception in the central dogma of Biology mRNA and rRNA are used in translation.

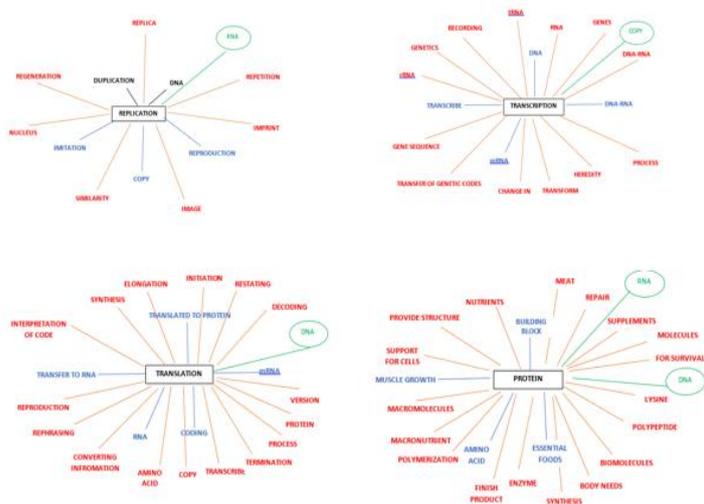


Figure 3. Concept Map with a Cut-off Interval of 1-2

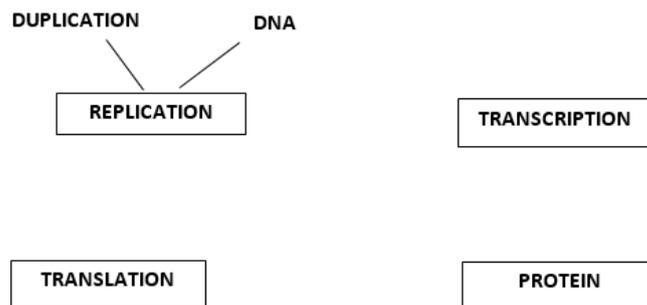


Figure 6. Concept Map with a Cut-off Point of equal of 6 over 6

Table 6 shows the words associated to the key concepts such as replication, transcription, translation and protein. The highest rank of associated word for replication is duplication, for transcription is DNA, for translation are transfer of RNA and coding and protein are building block, muscle growth, amino acid and essential food. While the Table 7 shows that words that are considered as NOT ACCEPTABLE or misconception. RNA is not associated with replication since DNA is used in this process. The same for DNA which is not used in translation but the RNA.

Table 6. Distribution of acceptable words to the key concepts

Concepts	Associated Words	f	
Replication	Duplication	10	
	DNA	6	
	COPY	5	
	Imitation	3	
	Reproduction	3	
	Regeneration	1	
	Increasing number	1	
	Similarity	1	
	Imprint	1	
	Repetition	1	
	Image	1	
	Replica	1	
	Transcription	DNA	5
Transcribe		3	
mRNA		3	
DNA-RNA		3	
Process		2	
RNA		2	
Gene sequence		2	
Transfer of genetic codes		2	
Reading of codes		2	
Genes		1	
Heredity		1	
Genetics		1	
Change in		1	
Transform		1	
Recording		1	
Copy		1	
Translation		Transfer of RNA	4
		Coding	4
		Translated to protein	3
		RNA	3

	mRNA	3
	Copy	2
	Reproduction	2
	Protein	2
	Converting information	2
	Restating	2
	Amino acid	2
	Interpretation code	2
	Process	1
	Transcribe	1
	Version	1
	Termination	1
	Initiation	1
	Elongation	1
	Synthesis	1
	Rephrasing	1
	Decoding	1
Protein	Building block	3
	Muscle growth	3
	Amino acid	3
	Essential food	3
	Nutrients	2
	Provide structure	2
	Support for cells	2
	Macronutrient	2
	Body need	1
	For survival	1
	Finish product	1
	Meat	1
	Synthesise	1
	Polymerization	1
	Molecule	1
	Supplements	1
	Repair	1
	Lysine	1
	Polypeptide	1
	Biomolecules	1
	Enzyme	1
	Macromolecule	1
	Albumin	1

Translation	DNA	5
	Conduct	1
	Reading	1
	Adaptation	1
	Elucidation	1
Protein	Energy-giving	2
	RNA	1
	DNA	1
	Nucleic acid	1

Table 8. Demographic Profile and Concept Perception of Science Teachers

Concept/ Demographic Profile	Total Computed Value	Df	Table value	Decision
Replication				
Age/ Perception	2.87	3	7.82	Accept null
Number of year teaching/ Perception	6.67	3	7.82	Accept null
Number of year teaching Biology/ Perception	4.76	3	7.82	Accept null
Undergraduate Major/ Perception	0.07	1	3.84	Accept null
Highest Educational Attainment/ Perception	4.29	2	5.99	Accept null
Transcription				
Age/ Perception	1.63	3	7.82	Accept null
Number of year teaching/ Perception	0.79	3	7.82	Accept null
Number of year teaching Biology/ Perception	7.37	3	7.82	Accept null
Undergraduate Major/ Perception	0	1	3.84	Accept null
Highest Educational Attainment/ Perception	0.49	2	5.99	Accept null
Translation				
Age/ Perception	3.16	3	7.82	Accept null
Number of year teaching/ Perception	0.79	3	7.82	Accept null
Number of year teaching Biology/ Perception	5.45	3	7.82	Accept null
Undergraduate	0.04	1	3.84	Accept

Table 7. Distribution of not acceptable words to the key concepts

Concept	Associated Words	f
Replication	RNA	2
	Meiosis	1
	Mitosis	1
	Mutation	1
	Protein	1
	Nucleus	1
Transcription	Copy	1
	rRNA	1
	tRNA	1
	Naming amino acids	1
	Inscription	1
	Evidence	1
	Archive	1
	Chronicle	1
	Clone	1

Major/ Perception				null
Highest Educational Attainment/ Perception	8.47	2	5.99	Reject null
Protein				
Age/ Perception	0.13	3	7.82	Accept null
Number of year teaching/ Perception	1.61	3	7.82	Accept null
Number of year teaching Biology/ Perception	2.14	3	7.82	Accept null
Undergraduate major/ Perception	0.96	1	3.84	Accept null
Highest Educational Attainment/ Perception	2.23	2	5.99	Accept null

Table 8 shows that null hypothesis should be accepted. This means that the demographic profile of the participants such as age number of years in teaching, number of years teaching biology, major during undergraduate studies and highest educational attainment are not related to their perception on the concepts replication, transcription and protein. This signifies that teachers' concept on replication, transcription, and protein are not affected whether they are old or young, the length or service, their degree program they have graduated with their specialization as well as their highest educational attainment. This only means that teacher's errors, misconceptions and alternative conceptions are attributed on the teachers themselves. Stern and Kampourakis (2017) stated that teacher's training or seminars cannot completely substantiate on what they have not understood correctly or did not learn during their undergraduate years. However, Smith et al., (2008) highlighted that there are some common errors among entry-level or newly hired teachers like explaining genetic material as something that codes for polypeptides only. This signifies that teachers' perception on concepts replication, transcription and protein could either be due to their personal attributes or due to being new in the system. With this, it is necessary for the teachers to

Limitations and Future Studies

The study is limited only to the four key words related to the concept Central Dogma. Further, Science textbooks are only limited to the textbooks utilized by the Science teachers as main teaching materials or reference. Further studies are encouraged especially on the important concepts in science and technology subjects and interview from the participants' first-hand experience in teaching the central dogma to validate result from the word association test.

solve and address misconceptions or alternative conceptions (Stern & Kampourakis, 2017). This study then recommends that teachers should improve oneself and admit to themselves concepts and topics that they do not fully understand like the central dogma of molecular biology. It is also suggested that school heads or school administrators should administer professional development trainings and seminars especially on the subject areas in which teachers might be lacking in understanding.

In contrast, on the perception of the science teachers to translation, it has shown that there is a significant relationship between highest educational attainment and on their perception on the concept translation for the computed value (8.47) is greater than the table value (5.99). This means that participants' highest educational attainment is related to their perception on the concept translation. This deviates with the other results shown in Table 8 where age, number of years in teaching, number of years teaching Biology and their specialization during undergraduate studies have no significant relationship to their perception on concept translation. This possibly occurs since teachers pursuing graduate studies tend to have more access to knowledge and there are limitless boundaries in comparison to those who have not studied. The limitations done by most teachers or professors in the way they teach a subject lead to lack of understanding (Thorne, Gericke, & Hagberg, 2013). Moreover, the length of training undergone by the teachers could also be the factor attributing to their knowledge or perception on certain topics (Stern & Kampourakis, 2017). This signifies that with the limitless information and knowledge as well as the length of training could create a difference affecting the perception of concepts. With this, it is suggested that teachers should enroll themselves to graduate studies in order to widen and deepen their understanding on central dogma of molecular biology.

Conclusion

Based on the results of the study, the researchers concluded that features of the science textbooks like presentation of the diagrams, elaboration on the figures, using analogies, and additional assessment tasks influence the learning of the learner. Moreover, science teachers have misconceptions on the concepts of the topic central dogma which might also taught to the students. And teacher's misconceptions if conveyed to the students will create a barrier that hinders learning.

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