Investigating the Cognitive Structure of Biology Preservice Teacher about Central Dogma of Molecular Biology Through Word Association Test

Investigating the Cognitive Structure of Biology Preservice Teacher about Central Dogma of Molecular Biology Through Word Association Test

D Sikumbang[1], I Rakhmawati[1], and T Suwandi[2*]

[1]Biology Education Department, Universitas Lampung, Street of Prof. Soemantri Brojonegoro No. 1 Bandar Lampung, Indonesia
[2]Biology Education Department, Universitas Pendidikan Indonesia, Street of Dr. Setiabudhi No. 229 Bandung, Indonesia

[*]trisuwandi@upi.edu

Abstract. In this study, word association test (WAT) was used to investigate the cognitive structure and level of understanding of biology preservice teacher students regarding the central dogma of molecular biology. Analysis of WAT's response words showed that the cognitive structure of students was grouped into 6 categories, namely: "molecules that play a role", "stages and processes that occur", "place in progress", "products", "synonyms/other terms", and " important role". The sentences analysis of the WAT response showed that biology preservice teacher students more often use the information processing mode "define" and "describe" in explaining the central dogma of molecular biology compared to "comparing" and "concluding". The results of the study concluded that cognitive structure and conceptual understanding of students on the topic of the central dogma of molecular biology were still deficient and not comprehensive. In addition, the implications of this study are presented at the end of the article.

1. Introduction

The branch of biology that is experiencing the most rapid progress in molecular biology [1]. These advances have resulted in the development of various genetic technology products and applications such as genetically modified organisms (GMOs), DNA fingerprinting techniques, screening of genetic diseases, gene therapy, and cloning [2]. For the 21st century generation, this progress must certainly be balanced with high scientific literacy, so that it can be a social control over issues circulating in society through social media [3]–[5]. In molecular biology, the term "central dogma" is known, which is a series of processes of gene expression or protein synthesis. The central dogma is described as a linear progression from a deoxyribonucleic acid (DNA) to ribonucleic acid (RNA) (through a transcription process) to a protein (through the translation process)[2]. The sequence of genetic information flow is the basis of various biological processes such as signal transduction, cell division, homeostasis in unicellular and multicellular organisms [6]. In addition, understanding the flow of genetic information is crucial for understanding more complex topics, such as heredity, phenotypic expression, developmental biology, and evolution [7].

Various studies have been conducted to measure students 'or students' understanding of the central dogma of molecular biology, both at the high school or college level. Previous research showed that students or college students, regardless of age, do not have a good or only partial understanding of DNA and genes. In addition, misconceptions about central dogma are maintained by students at least in the Basic Biology course [8-9]. The lack of students' understanding of the central dogma of molecular

biology turns out to be difficult to update with further learning models. Even after taking Basic Biology courses, students find it difficult to master the central concept of molecular dogma. Several factors such as the complexity of vocabulary or terminology and the difficulty of interpreting the arrow as a representation of the linear model are the reasons for the difficulty in studying the topic of central dogma and the least increase in student learning outcomes on the topic [10]. This indicated that the conceptual structure or cognitive structure of students regarding the central dogma of molecular biology was not good enough, thus impacting on the lack of understanding of concepts and the emergence of misconceptions on the concept of the central dogma of molecular biology.

One method used to investigate cognitive structures is the word association test [11–13]. This test can also be used to analyze misconceptions [14–17]and evaluate conceptual changes [18]. Research using WAT was applied to various subjects, such as junior high school students [15, 19], high school students [20], preservice teacher[11, 13, 18, 19], and teachers [19]. However, the studies of the cognitive structure of biology preservice teacher regarding the central dogma of molecular biology using WAT have not been widely reported. Therefore, this study will investigate the cognitive structure and level of understanding of biology preservice teacher students regarding the central dogma of molecular biology using WAT.

2. Research Methods

2.1. Research design
Qualitative methods are used in this study [21]. The basic objective of qualitative research is not to obtain generalizable results, but to present descriptive and realistic cases related to the problem investigated. Given the reliability and validity of results, it is important to provide as much detail and direct data as possible. Thus, in this study, the views given by prospective biology teachers regarding the central dogma of molecular biology are described and the results obtained are not generalized.

2.2. Participant
This study involved 68 biology preservice teacher students in the first year in the Biology Education study program, the Teaching and Education Faculty, the University of Lampung who had taken the course in Cell Biology. The average age of participants is 18.1 years, with a range of 17-19 years. Female students are the most involved participants in this study, as many as 50 students (85.3%). However, gender differences were not evaluated in this study. Students involved in the study were told by researchers about the purpose of the study and how to complete the measurement tool.

2.3. Research Instruments
In this study, to collect detailed data about the cognitive structure of prospective teacher biology students regarding the central dogma of molecular biology used by WAT as a data collection tool. In this study, participants were asked about the central dogma of molecular biology to solve WAT. In this test, one keyword was used as a stimulus, namely: the central dogma of molecular biology.

The word association test consists of two stages. First, participants are asked to indicate the concepts in their minds related to the word stimulus as an answer, within a certain period [22]. Participants were asked to write in 60 seconds ten words that came from their minds when they read or heard the concept of the central dogma. Second, participants are asked to write sentences related to the key concept in 30 seconds and at this data analysis stage written sentences are checked one by one. This was because the response sentence related to the key concept may also be just the product of the association without a meaningful relationship with key concepts. In addition, because the response sentence will be more complex and have a high-level structure compared to the word response, whether the sentence was scientific or not, or whether the sentence includes misconceptions that affect the evaluation process.

2.4. Validity and Reliability of Data Collection Tools
Two stages were applied to ensure the validity of the research results, namely: (a) data coding and analysis (how categories of cognitive structure are obtained) were discussed in detail, and (b) the views of biology preservice teacher students who were believed to be the best representation of each category obtained through research that chosen as an example, and these examples were presented in the findings

section [23]. For research reliability, the codes and categories obtained from the two researchers were compared to confirm whether the codes obtained in each category of cognitive structures represented these categories. The code list is finalized after two experts in the field of biology code data individually. Data analysis reliability is calculated using the formula [Amount of agreed data / [(Total data) x100] [24]. The average reliability obtained from two experts was 95%.

2.5. Data analysis technique

Content analysis method consists of four stages, namely: (a) coding data, (b) finding themes/categories, (c) compiling coding and themes/categories, and (d) identifying and interpreting findings used in this study [25]. Prior to the analysis, participants' answer sheets were numbered 1 to 68. The data obtained through WAT were analyzed to get the number of answers/response words (response words), a number of words (concepts), and semantic relationships [26]. Response words that have the same meaning were classified in one concept in a category. The response words that were considered not in accordance with the term concept of the central dogma of molecular biology and only repeated once were not analyzed. The list of response words was arranged in appropriate categories. Furthermore, the frequency table was arranged (Table 1) and the cognitive structure model was made based on the percentage (Figure 1). Meanwhile, the response sentence was analyzed as follows. First, sentences were categorized into three classes, namely: correct scientific knowledge (correct definition or correct use of terms); misconception (incorrect scientific explanation); and irrelevant or meaningless (off-topic sentences). Then, the sentence was examined from the angle of the information processing mode, for example, defining, rendering, comparing, and concluding [11, 27]. Examples of response sentences are presented in quotations and followed by the participant code, for example: "..." P (18).

Table 1 Distribution of biology preservice teachers' cognitive structure about dogma central of molecular biology

Categories	Concepts under categories	Frequencies	Total frequencies of the category
1. The molecules that play a role	DNA	54	
	RNA	40	
	Amino acid	29	
	mRNA	27	
	tRNA	20	
	RNA polymerase	18	
	Enzyme	14	257
	Codon	18	
	ATP	10	
	rRNA	9	
	Anticodon	6	
	Gene	5	
	Intron	3	
	Exon	2	
	Terminator	2	
2. Stages and processes that occur	Transcription	52	
	Translation	51	
	Initiation	29	
	Elongation	24	232
	Termination	23	
	Post translation	18	
	Post transcription	17	
	Replication	12	
	Splicing	3	
	Protein trafficking	3	
3. Place occur	Ribosome	24	
	Nukleus	18	57
	Cytoplasm	7	

Categories	Concepts under categories	Frequencies	Total frequencies of the category
4. Product	Cell	6	
	Lysosome	2	
	Protein	24	32
	Polypeptide	8	
5. Synonyms / other terms	Synthesist protein	14	20
	Gene expretion	6	
6. Important role	Cell development	3	5
	Cell compiler	2	
Total	**36 konsep**	**603**	**603**

3. Result and Discussion

The results of data analysis, the first category as well as the dominant category related to the central dogma of molecular biology are "molecules that play a role" (f = 257). In this category many participants wrote "DNA", "RNA", "amino acid", "mRNA", and "tRNA". There are a number of response words written only by participants and derived from this category, such as "antisense", "transcription factors", "sequences", "TATA box", "DNA polymerase", and "helicase".

The second category that is formed from the words response is "the stages and processes that occur" (f = 232). The word "transcription" and "translation" are the most dominant concepts in this category. In addition, the word "mutation" is not classified in this category.

The third category related to the central dogma of molecular biology is "place occur" (f = 57). The word "ribosome" and "nucleus" are the two most dominant concepts in this category. In addition, there are several response words such as "chloroplasts", "mitochondria", "organisms", "endomembrane systems", and "spliceosomes" not classified in this category.

In the fourth category, participants present associations about "products" (f = 32). Most participants answered, "protein" and "polypeptide" as concepts related to the central dogma of molecular biology. In this category, no response words were found which were not included in the fourth category.

The fifth category related to the central dogma of molecular biology is "synonym / another term" (f = 20). Participants wrote, "protein synthesis" and "gene expression" as concepts related to the central dogma of molecular biology. In this category, no response words were found that were not included in the fifth category.

In the sixth category, participants mentioned associations about "important roles" (f = 5). The concepts that fall into this category are "cell development" and "cell compiler". Meanwhile, "phenotypic" and "metabolic" answers are not included in this category.Based on the evaluation of the results above it can be investigated that the cognitive structure of biology preservice teacher students regarding the central dogma of molecular biology is collected in a particular theme or category. In this context, a cognitive structure model for prospective biology teachers is made about the central dogma of molecular biology based on the evaluation of data obtained from WAT (Figure 1).
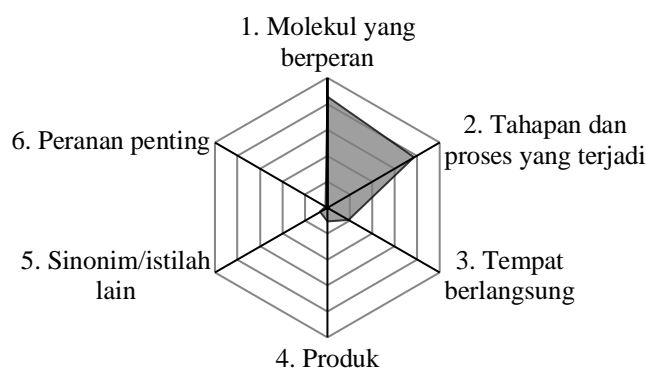

Figure 1. Biology preservice teachers' cognitive structure about dogma central of molecular biology.

From these results, it is observed that the category of "molecules that play a role" and "the stages and processes that occur" have a close connection in the cognitive structure of prospective biology teacher students about the central dogma of molecular biology. It was also observed that prospective biology teacher students have insufficient knowledge of the central dogma of molecular biology in the category of "place", "product", "synonym / another term", and "important role". In addition, it is observed that prospective biology teacher students have insufficient knowledge related to response words, such as: "exon", "intron", "transcription factor", "splicing", "protein trafficking", "mutation", "Endomembrane system", "spliceosome", "phenotype" and "metabolism". Based on this, it can be stated that the cognitive structure and conceptual understanding students on the topic of the central dogma of molecular biology is still deficient and not comprehensive even after attending the Cell Biology lecture.

Meanwhile, the results of the analysis of the sentence responses obtained from WAT regarding the central dogma of molecular biology are presented in Table 2.

Table 2 Biology preservice teachers' degree of understanding regarding dogma central of molecular biology

	Defining	Describing	Comparing	Interfering	Total
Correct	17 (25)	21 (31)	2 (3)	7 (10)	47 (69)
Misconception	6 (9)	8 (12)	0	0	14 (21)
Irrelevant	2 (3)	3 (4)	1 (1)	1 (1)	7 (10)
Total	28 (37)	34 (47)	3 (4)	8 (12)	68 (100)

*Numbers in brackets are the percentages

Based on Table 2 it is known that most participants used the information processing mode "defining" and "describing" to explain the central dogma of molecular biology, while the mode of "comparing" and "concluding" was used little. More than some participants (69%) were able to write a correct explanation about the central dogma of molecular biology. Here are the examples:
"Central dogma is a form of gene expression, which is a process of translating genetic information (in the form of base sequences into DNA or RNA) into proteins" (P4). (Participants write the definition of the central dogma of molecular biology and mention other terms).

> "...*Gene expression is a mechanism in cells that takes place in a complex and systematic way, covering replication, transcription, post-transcription, translation, and modification of proteins*" (P33). (Participants write down cellular processes that occur in the process of gene expression).

> "...*Important components involved in gene expression include: DNA, RNA (mRNA, rRNA, tRNA), ATP, and polymerase enzymes* " (P23). (Participants write important components in the central dogma of molecular biology).

> "...*In central dogma, DNA acts as a command center and controls protein synthesis that takes place in the nucleus. ...*" (P3). (Participants wrote the role of DNA in protein synthesis).

> "...*In addition, the intractable dogma is a reflection of how genes work in regulating the nature (phenotype) of an organism*" (P56). (Participants wrote the importance of gene expression for organisms).

However, there are some explanations that are classified as misconceptions and irrelevant, respectively 21% and 10%. Here are the examples:

> "*Central dogma is the process of converting amino acids contained in DNA into proteins in the body, which requires the role of DNA, RNA, and enzymes*" (P17). (Participants write the definition of the irrelevant central dogma of molecular biology: DNA does not contain amino acids, but genes as genetic information).

"*Central dogma occurs in the organelles precisely inside the ribosome*" (P51). (Participants are not right to write down the place of the central dogma, because the central dogma does not only involve the ribosome but also the nucleus and endomembrane system).

"*...Protein synthesis begins with the DNA replication stage and then enters the transcription stage* (P52). (The participant is not right in writing the initial stages of protein synthesis, protein synthesis should begin with transcription).

"*...Transcription is the process of copying data contained in the DNA sense chain. ...*"(P24). (Participants are not right in writing a description of the transcription process. The transcribed DNA strands are not sensed strands, but antisense strands (3' – 5') DNA).

"*...The result of this process is a protein that has been mechanically and chemically processed inside the cell*" (P20). (Participants wrote unclear sentences regarding the process of modifying the chemistry of the translational post protein).

Based on the evaluation of the results of the sentence response analysis obtained from WAT, it can be investigated that biology preservice teacher students most often use the information processing mode "define" and "describe" in explaining the central dogma of molecular biology. Both of these information processing modes are considered to have a lower cognitive level than comparing and concluding. It was also observed that some students have cognitive structures with poor conceptual validity. In addition, it was observed that some students failed to make effective and meaningful sentences regarding the central dogma of molecular biology. Therefore, based on the results obtained from this study it can be stated that the strategy of organizing information on prospective biology teacher students was still deficient during the recall information process.

The results of the response sentence analysis obtained from WAT also indicate that some students demonstrate misconceptions on the topic of the central dogma of molecular biology. Misconceptions on the topic of genetics were also investigated both using WAT [28] and other techniques, such as drawing-writing tests [3, 4, 5, 29] and flow maps [30]. The concept of molecular basis inheritance and exchange of genetic information was a topic that was difficult for biology students [31- 32]. The concept of central dogma was a comprehensive and multidisciplinary subject that includes cells (structures and organelles), organic compounds, nucleic acids (DNA and RNA), proteins, chemical digestion, and enzymes, and was connected to other disciplines such as chemistry [30, 33]. In addition, the topic of the central dogma of molecular biology has the complexity of terminology and symbol of representation [6, 34]. Some of these reasons are thought to cause the inadequate cognitive structure of students regarding the central dogma of molecular biology, thus affecting the deficiency of conceptual understanding and the emergence of misconceptions.

The inadequate cognitive structure of students regarding the topic of central dogma in molecular biology indicates the need for improvement in the learning process. So far, many students struggle to learn concepts related to gene structure and expression, without understanding the importance of genetic information flow in the context of gene regulation, which is an important concept in molecular biology [6, 35, 36]. Therefore, the results of this study can be used as a basic or needs analysis to develop a meaningful learning design or model, so that students can be facilitated in developing relevant scientific knowledge and comprehensively organized knowledge.

The results of this study indicate that it is important for educators to detect changes in the cognitive structure of students regarding a concept. One of the easiest and most commonly used techniques to determine an individual's cognitive structure about a concept is WAT. In its application, this test can be applied before learning to detect prior knowledge of students or after learning to control changes in the cognitive structure of students. The combination with other techniques to map out more detailed cognitive structures was suggested.

4. Conclusion

By using WAT, the cognitive structure of biology preservice teacher students about the central dogma of molecular biology was grouped into 6 categories, there are: "molecules that play a role", "stages and processes that occur", "place", "products", "synonyms / other terms "And" important role ". Biology preservice teacher students more often use the information processing mode "define" and "describe" in explaining the central dogma of molecular biology compared to "comparing" and "concluding". A small percentage of students show misconceptions on the topic of the dogma of the central dogma of molecular biology. Based on this, it can be stated that the cognitive structure and student' conceptual understanding of the topic of the central dogma of molecular biology are still deficient and not comprehensive.

References

[1] G. Karp *Cell and Molecular Biology Concepts and experiments*
[2] Albert, Johnson, Lewis, Raff, Roberts and Walter 2008 *Molecular Biology of The Cell*
[3] B. Agorram & E. N. Superieure, "University students ' conceptions about the concept of the gene : Interest of historical approach," no. July 2014.
[4] V. Dawson & R. Schibeci 2014 Understanding of biotechnology *International Journal of Science Western Australian school students* 37–41
[5] T. Suwandi & U. P. Indonesia 2018 Biology Education Students Mental Models
[6] L. K. Wright, J. N. Fisk & D. L. Newman 2014 DNA → RNA : What Do Students Think the Arrow Means ? **13** 338–348
[7] A. G. Briggs, S. K. Morgan, S. K. Sanderson & M. C. Schulting 2016 Supplemental Materials for Tracking the Resolution of Student Misconceptions about the Central Dogma of Molecular Biology Central Dogma concept map **20036** 2016
[8] G. Marbach-ad 2010 Attempting to break the code in student comprehension of genetic concepts 37–41
[9] Shaka & Bitner 1996 Construction and validation of a rubric for scoring concept maps
[10] G. J. Kelly *et al* 2005 An Exploration of Young Children's Understandings of Genetics Concepts from Ontological and Epistemological
[11] F. Aydin & M. F. Taşar 2010 An Investigation Of Pre-Service Science Teachers ' Cognitive Structures and Ideas About The Nature Of Technology Fen Bilgisi Öğretmen Adaylarını n Teknolojinin Doğası Hakkındaki Bilişsel Yapıları ve Görüşleri
[12] H. Kurt 2007 Determining Biology Teacher Candidates' Conceptual Structures about Energy and Attitudes Towards Energy 399–423
[13] H. Kurt 2013 Determining Cognitive Structures and Alternative Conceptions on the Concept of Reproduction (The Case of Pre-Service Biology Teachers) **4** 9 572–587
[14] T. Hovardas & K. J. Korfiatis 2006 Word associations as a tool for assessing conceptual change in science education **16** 416–432
[15] C. Nakiboglu 2008 Using word associations for assessing non-major science students ' knowledge structure before and after general chemistry instruction : the case of atomic structure 309–322
[16] Z. D. Akbar, C. Education & U. Riau 2017 The Identification Of Misconception Of Chemical Equallibrium Material By Using Diagnostic Three-Tier Multiple Choice Test Of The Second Year Students Of Sma Negeri 2 Pekanbaru Kimia Menggunakan Tes Diagnostik Pilihan Ganda Tiga Tingkat (Three-Tier Multiple Choice) Pada Peserta Didik Kelas Xi Mia Sma Negeri 2 Pekanbaru 1–15
[17] Irwandani, & Rofiah, S 2015 Pengaruh Model Pembelajaran Generatif Terhadap Pemahaman Konsep Fisika Pokok Bahasan Bunyi Peserta Didik MTS Al-Hikmah Bandar Lampung *Jurnal Ilmiah Pendidikan Fisika Al-BiRuNi* **4** 2 165–177
[18] E. Ö. Yücel & M. Özkan 2015 Determination of secondary school students ' cognitive structure, and misconception in ecological concepts through word association test **10** 5 660–674
[19] Z. Kostova 2008 Word Association Test for Study- ing Conceptual Structures of Teachers and Students **2** 2 209–231.
[20] E. Yucel 2016 Educational Research and Reviews Determination of secondary school students' cognitive structure, and misconception in ecological concepts through word association test

[21] J. Creswell 2012 *Educational Research: Planning, Conducting and Evaluating Quantitative and Qualitative Research*

[22] E. Gussarsky & B. S. Israel 1990 On The Concept 'Chemical Equilibrium': The Associative Framework **27** 3 197–204

[23] R. Jenkins & R. A. Jenkins 2004 Reliability in Coding Open-Ended Data : Lessons Learned from HIV Behavioral Reliability in Coding Open-Ended Data : Lessons Learned

[24] M. Miles, M. Huberman & J. Saldana 2014 *Qualitative Data Analysis*

[25] A. Strauss & J. Corbin 2007 *Basic of Qualitative Research*

[26] B. Atasoy, H. Akkus & H. Kadayifci 2016 The effect of a conceptual change approach on an understanding of students ' chemical equilibrium concepts **5143**

[27] E. Atabek-yigit 2016 Investigating Cognitive Structures in Some Basic Chemistry Concepts Via Word Association Test Kelime İlişkilendirme Testi Aracılığıyla Bazı Temel Kimya Kavramları Konusundaki Bilişsel Yapının Araştırılması **15** 4 1385–1398

[28] M. Bahar & A. H. Johnstone 1999 Investigation of students ' cognitive structure in elementary genetics through Investigation of students ' cognitive structure in elementary genetics through word association tests

[29] A. Saka, L. Cerrah, R. Ali & A. Ayas 2006 A Cross-Age Study of the Understanding of Three Genetic Concepts : How Do They Image the Gene, DNA, and chromosome ? **15** 2 192–202

[30] C. Gercek 2013 Prospective Teachers 'Cognitive Structures Concerning Protein Synthesis and Their Degree of Understanding 19–30

[31] D. Allchin No Title

[32] D. Murni, P. Studi, P. Biologi, U. Sultan & A. Tirtayasa 2013 Identifikasi Miskonsepsi Mahasiswa Pada Konsep Substansi Genetika Menggunakan Certainty of Response Index (CRI) 205–212

[33] A. B. Witarto 2010 Seminar Nasional Pendidikan Biologi FKIP UNS 2010 *Seminar Nasional Pendidikan Biologi FKIP UNS 2010* 15–16

[34] T. J. Santoso 2013 Aplikasi Teknik Molekuler Untuk Analisis Genetik Tomato Leaf Curl Virus Application of Molecular Technique for Genetic Analysis of Tomato Leaf Curl Virus **2**

[35] J. Khodor, D. G. Halme & G. C. Walker 2004 A Hierarchical Biology Concept Framework : A Tool for Course Design **3** 111–121

[36] I. Ruspita 2006 Menyelami Ilmu Biologi Molekuler Dan Genetika Dari Buku Genomes 3 **5** 2