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ASSESSING UNDERGRADUATES' MISCONCEPTIONS ON CENTRAL DOGMA OF MOLECULAR BIOLOGY USING A 3-TIER DIAGNOSTIC TEST

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Abstract: Misconceptions can hinder students' learning of biology, especially in the central dogma of molecular biology due to its connection with other topics. Studies have shown that Philippine high school students harbour significant misconceptions regarding genetics, including the central dogma. This study aims to develop a three-tier diagnostic test to identify misconceptions carried forward to undergraduate students enrolled in biologically related courses, leading to the development of the Central Dogma of Molecular Biology Questionnaire (CDMBQ). This study found that the CDMBQ has very good reliability (a = 0.88) and moderately positive construct validity (r = 0.4). It also revealed that the respondents have a low understanding of the central dogma (mean = 4.76), and they have acquired misconceptions pertaining to transcription, types of RNA, and translation. Lastly, perception items showed students have forgotten central dogma concepts, display confusion about the topic, and maintain neutral sentiments about their science teacher as well as have neutral feelings about their understanding of the central dogma. Nonetheless, they expressed interest in studying its concepts. These results confirm the reliability and validity of the CDMBQ for assessing misconceptions surrounding the central dogma of molecular biology.

Keywords: Three-tier diagnostic test, misconception, the central dogma of molecular biology.

Introduction

Students often develop their own explanations for different phenomena in the world even before they enter the classroom. These ideas or understandings can be a product of how they observe things around them. Thus, these ideas are different from what the scientific community deems to be true, which can be considered as misconceptions or alternative conceptions. A misconception can be defined as an individual's discernment of occurrences happening in the mundane world that are not consistent with the scientific explanation of the phenomena (Modell *et al.,* 2005). Misconceptions are also considered barriers to learning (Ausubel *et al.,* 1978). Additionally, if a student has a preconceived notion of the lesson, it is difficult for a teacher to correct or change it (Schneps & Sadler, 1989).

One factor contributing to misconceptions among students in the Philippines is the presence of some elementary science reference materials that themselves contain misconceptions. This issue becomes more complex when non-science teachers are tasked with teaching these science subjects and have to rely on these reference materials, often without the capacity to rectify these misconceptions, leading to the proliferation of errors in students' understanding of scientific concepts (Raymundo, 2008).

Within the field of biology, genetics stands out as a subject with a high level of misconceptions among Filipino high school students. One study found that 55% of the respondents exhibited a high level of misconception. Notably, the topic of genetics had the highest overall percentage of misconceptions in the field of biology, with 55% classified as a high level of misconception. Following genetics, botany (44.10%), ecology (43.50%), and zoology (38.30%) were the next three subjects, all categorised as having moderate levels of misconceptions. In this regard, misconceptions about genetics can be problematic due to their relationship with other concepts in biology (Rogayan & Albino, 2019).

Understanding the flow of genetic information inside the cell, also known as the central dogma of molecular biology, is crucial to understanding more advanced topics, such as inheritance, phenotypic expression, developmental biology, and evolution. Identifying and correcting these misconceptions can lead to an improvement in students' learning and promote a deeper understanding of different topics in biology (Brigss *et al.,* 2016). These misconceptions that students develop in high school, if not promptly addressed, have the potential to persist and accompany them when they transition to college. To identify if these misconceptions persist in undergraduate students, the use of a diagnostic exam pertaining to the central dogma of molecular biology is important, especially for students who enrolled in a biology-related course in college, where the concepts of the central dogma are frequently touched upon. Hence, this study focuses on the development of the Central Dogma of Molecular Biology Questionnaire (CDMBQ), which includes a three-tier diagnostic test designed to assist educators in pinpointing students' misconceptions and identifying specific aspects of the central dogma that need to be revisited. This study's outcomes are intended to facilitate educators in the construction of a diagnostic examination that identifies misconceptions related to the central dogma of molecular biology.

In line with the stated purpose of the study, the following are the different questions that need to be addressed:

1. Is the Central Dogma of Molecular Biology Questionnaire (CDMBQ) a valid and reliable instrument to identify misconceptions?
2. What is the level of understanding among undergraduate students regarding the central dogma of molecular biology?
3. What are the most common misconceptions among undergraduate students regarding the central dogma of molecular biology?
4. What are students' perceptions regarding the learning of the central dogma of molecular biology?

Materials and Methods

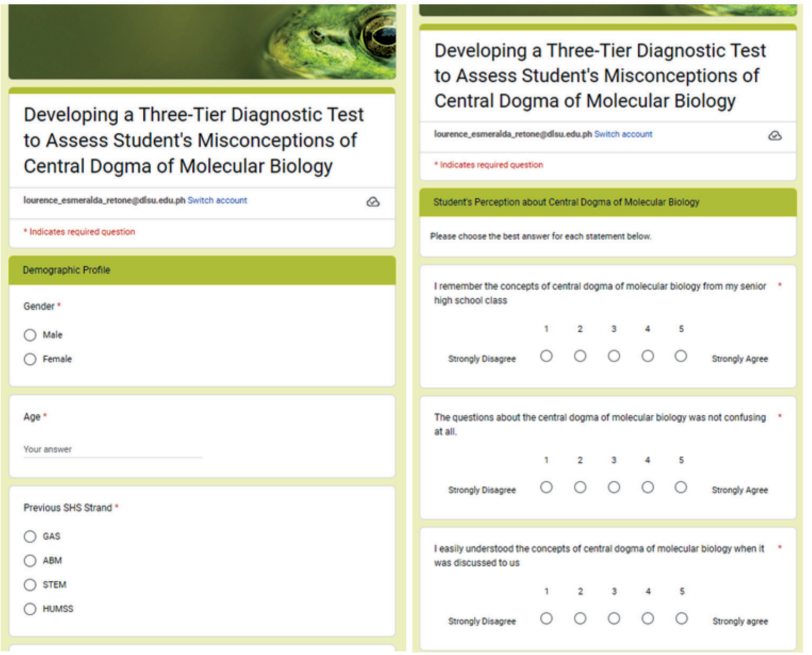
Sampling and Participants

This study used a descriptive research approach using quantitative techniques. It aims to assess undergraduate students' misconceptions regarding the central dogma of molecular biology. Purposive sampling was utilised to select the respondents for this study, who are first-year undergraduate students enrolled in biology and/or medical courses. Due to time and availability constraints, only 109 college students from various universities in Metro Manila, the Philippines, participated, regardless of sex, previous senior high school strand, or senior high school background. The participants were sent consent letters via Google Forms, explaining that their participation was entirely optional and that they could opt out at any time.

Research Instruments

This study used the Central Dogma of Molecular Biology Questionnaire (CDMBQ), a researcher-developed questionnaire comprising a 4-item section for demographic profile information [Figure 1 (A)], a 5-item section measuring students' perception of the central dogma of molecular biology using a 5-point Likert scale ranging from 5 to denote strongly agree to 1 to denote strongly disagree [Figure 1 (B)], and a 15-item 3-tier diagnostic test on the central dogma of molecular biology (Figure 2). This instrument was designed to explore students' demographic profiles and identify their misconceptions and levels of understanding and perception.

Figure 2 shows the components of the three-tier diagnostic test: (1) Tier 1 items, represent knowledge-based questions; (2) Tier 2 items are the explanations for the answers provided in Tier 1; and, (3) Tier 3 items evaluate respondents' confidence levels. In order to assess misconceptions held by the respondents, the researchers developed item sets for every identified misconceptions on the topic of the central dogma of molecular biology. These items were formulated with the help of literature collected from various sources, including



A B

Figure 1: A is a screenshot of the demographic profile section, and B is a screenshot of the questionnaire measuring students' perception of the central dogma of molecular biology

Google Scholar, Scopus, EBSCOhost, and ProQuest, spanning the years 2000 to 2021, to ensure a comprehensive range of studies that align with the requirements for creating test items. The search keywords that were used were "misconception", "biology", "diagnostic test", and "central dogma of molecular biology". Additionally, interviews were conducted with biology teachers to identify topics in which they observed misconceptions while teaching the central dogma of molecular biology in their classes. The researchers purposely chose teachers who have been teaching general biology in senior high school and have taught the central dogma of molecular biology in their classes. Due to time constraints, this interview process involved two public school teachers and three private school teachers.

Procedure

The study consisted of two phases. In Phase 1, the researchers identified literature on misconceptions in biology and their causes. Afterwards, biology teachers were interviewed to gather their input for the development of the items in all tiers of the three-tier test. The topics that were identified as containing misconceptions, derived from literature review and teacher interviews, included transcription, DNA replication sequences of events within the central dogma, and types of RNA, as well as translation, as presented in Table 1.

Following the development of the instrument, expert biology teachers assessed it for its face and content validity. Subsequently, a pilot study involving 39 participants in one section was conducted to assess construct validity and reliability. Upon confirming that the instrument is valid and reliable, the researchers proceeded to Phase 2, where the instrument was administered to 109 undergraduate participants. Data collected from all sections of the questionnaire were analysed to determine the level of understanding, pinpoint topics with misconceptions, and assess the perceptions of undergraduate students regarding the central

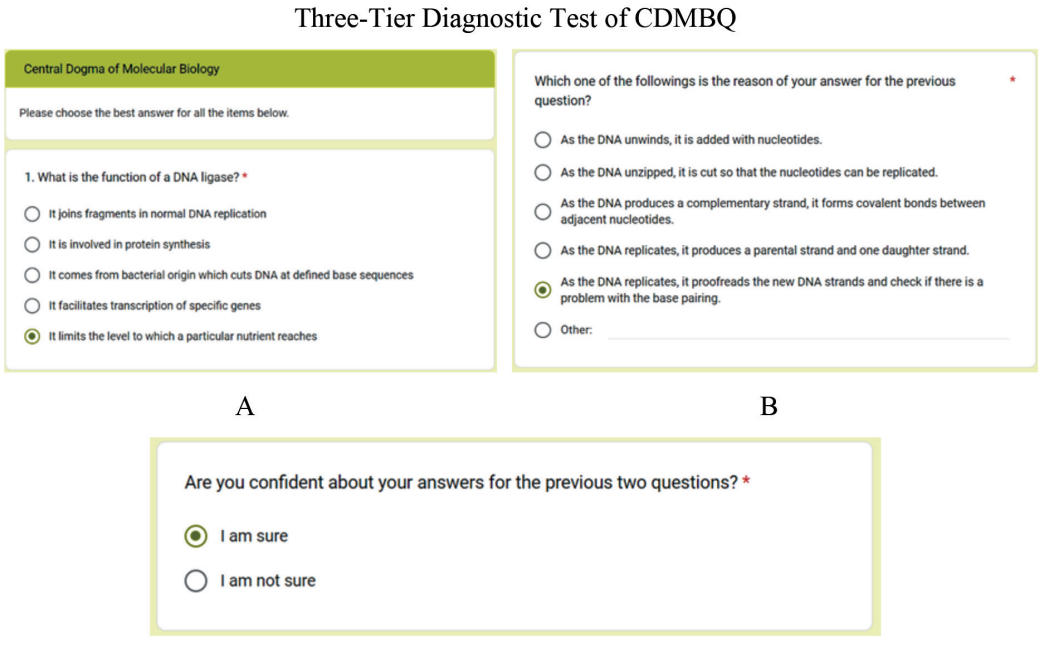


Figure 2: A is a screenshot of a first-tier item; B is a screenshot of a second-tier item; and, C is a screenshot of a third-tier item on the central dogma of molecular biology

Table 1: CDMBQ Knowledge Questions

Item No.	Questions	Concept
1	What is the function of a DNA ligase?	DNA replication
2	Which of the following is the best description of DNA replication?	DNA replication
3	What is the description of the "central dogma" of molecular biology as described by Watson and Crick?	Sequence of events in the central dogma
4	What type of RNA carries the information that specifies a protein?	Types of RNA
5	What process converts the mRNA "message" into a sequence of amino acids?	Types of RNA
6	What is the three-base sequence (loop) in tRNA that is complementary to a three-base sequence in mRNA?	Translation/protein synthesis
7	Why do we describe tRNA as a "bilingual" molecule?	Types of RNA
8	Which of the DNA strands will pair with the DNA sequence ATGCATGC?	Transcription
9	Why would it take more energy to separate DNA with the sequence GCGCGCGC and its complementary strand than the sequence ATATATAT and its complementary strand?	Transcription

10	Which of the following mRNA strands will pair with these tRNA anticodons AUGCAUGCA?	Translation/protein synthesis
11	What process is blocked by Amanatin, a toxin found in the death cap mushroom *Amanita phalloides* that inhibits RNA polymerase?	Transcription
12	Which of the following statements about DNA sequence is correct?	DNA replication
13	Which of the following codes for the methionine are also known as the "start codon"?	Translation/protein synthesis
14	Which of the following best describes the relationship between DNA, proteins, and RNA?	Overview of central dogma
15	How many amino acids are added in a polypeptide chain by the sequence AUGCUUGACUAAGUCCCC from the start codon to the stop codon?	Translation/protein synthesis

Note: The questions in the table are found in the 1st Tier knowledge questions of the CDMBQ

dogma of molecular biology.

Data Analysis

The Central Dogma of Molecular Biology Questionnaire utilised descriptive statistics to analyse the various data collected. Descriptive statistics were utilised to assess the demographic profile data, enabling the identification of the percentages related to gender and undergraduate degree, providing insights into the study's responses. To evaluate the validity and reliability of the items, Cronbach's alpha reliability was calculated on the 3-tier test and perception items of the questionnaire; four types of variables were used to analyse the data: (1) 1st-tier items (scores in multiple-choice conceptual questions), (2) 2nd-tier items (scores in conceptual questions and the reason for selecting the answer to the first question was considered), (3) 3rd-tier scores or the confidence tier scores, and (4) all-tier items.

To evaluate the construct validity of the test items, Pearson's correlation was calculated between Score 2 and the respondents' confidence level. When examining the percentages of false positives in respondents' answers, the correct answer for the 1st tier, incorrect reasoning for the 2nd tier, and an uncertain answer for the 3rd tier were used. Conversely, for false negatives, the wrong answer to the 1st tier was used, with the correct reason in the 2nd tier and a certain answer in the 3rd tier. The percentage indicating a lack of knowledge was measured using either of the following: (a) The correct answer to the 1st tier with incorrect reasoning in the 2nd tier; (b) the incorrect answer to the 1st tier with correct reasoning in the 2nd tier and uncertain in the 3rd tier; or, (c) the incorrect answer in the 1st and 2nd tiers and uncertain in the 3rd tier. Furthermore, when analysing items where students exhibited the highest level of misconception, the incorrect answers of the 1st tier were combined with the incorrect reasoning of the 2nd tier and a certain answer in the 3rd tier. Finally, in assessing students' perception of studying the central dogma of molecular biology, the mean and standard deviation of each perception item were used and interpreted.

Results and Discussion

Demographic Profile

The study involved 29.36% male respondents and 70.64% female respondents from a total population of 109, where 17.43% of them attended public senior high schools and the remaining 82.57% attended private senior high schools. In terms of senior high school strands, 83.49% of the respondents were enrolled in STEM, 7.34% each were enrolled in ABM and GAS, and only 1.83% in HUMSS. Figure 3

shows the percentages of their undergraduate courses. Specifically, 55.96% were pursuing a Bachelor of Science degree in Biology, 20.18% were pursuing degrees in Dentistry, and 11.93% were pursuing undergraduate degrees in Nursing.

Reliability of the Items in the Three-Tier Test

The results presented in Table 2 revealed the Cronbach's alpha reliability coefficients for the three tiers of the test. For Tier 1, which assesses knowledge, the coefficient (a) was 0.72, indicating good reliability. For Tier 2, which includes knowledge and reasoning items, the coefficient was 0.82, signifying very good reliability. The third tier, focusing on confidence level items, exhibited a coefficient of 0.88, also indicating very good reliability. Lastly, when considering all items across the three tiers, the overall reliability coefficient was 0.88, affirming very good reliability (Cronbach, 1951). These results demonstrate that all items within the three-tier test exhibit reliability as a tool for identifying misconceptions, knowledge gaps, and the level of understanding among the participants.

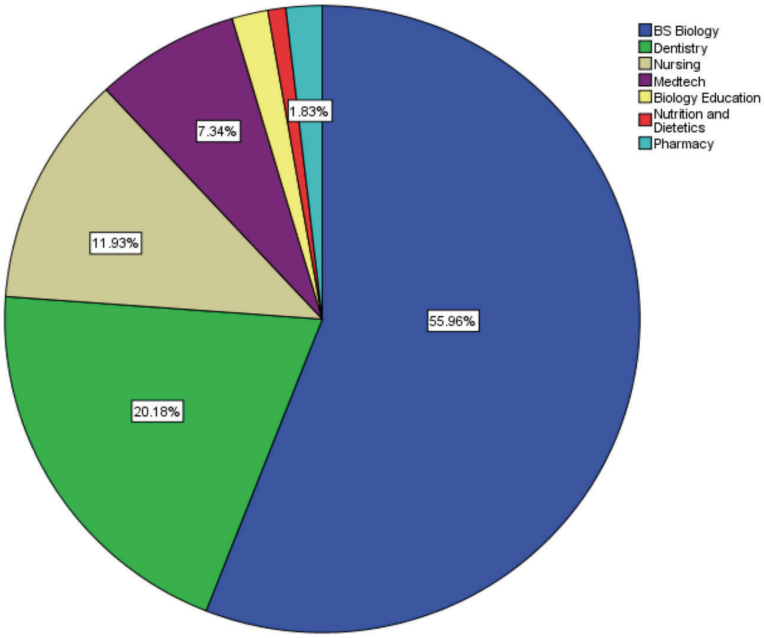


Figure 3: Respondents' undergraduate courses

Table 2: Reliability of CDMBQ

CDMBQ Items	Description	Cronbach's Alpha	Number of items	Interpretation
Tier 1	Knowledge	0.72	15	Good reliability
Tier 2	Knowledge and Reasoning	0.82	30	Very good reliability
Tier 3	Confidence Level	0.88	15	Very good reliability
All 3 Tiers	Knowledge and Reasoning and Confidence Level	0.88	45	Very good reliability

Note: Interpretation based on Cronbach (1951)

Construct Validity of the Three-Tier Test

The scatter plots presented in the accompanying figures serve as visual representations of the construct validity of the test items within the CDMBQ. These plots were generated to assess the correlation between the Tier 2 scores and the confidence level scores. This correlation is a quantitative approach to establishing the construct validity of the CDMBQ (Pesman & Eryilmaz, 2010). In Figure 4, it can be seen that the Tier 2 scores and respondents' confidence level scores have a positive correlation, supported by Pearson's correlation coefficient of r = 0.4. This value represents a moderate level of reliability, suggesting that students who answer the knowledge and reasoning questions correctly tend to be confident in their responses because they have a solid understanding of the subject matter. This correlation reinforces the validity of the constructed test items.

False Positives, False Negatives, and Lack of Knowledge

Table 3 provides an overview of the percentages for false positives, false negatives, and lack of knowledge in the CDMBQ, which is a key characteristic of a three-tier test. Notably, Items 1 (22.9%), 7 (13.8%), 9 (15.6%), 14 (29.4%), and 15 (18.3%) exhibited the highest percentages of false positives, with a mean of 10.46 and a Standard Deviation (SD) of 1.7. It's worth noting that according to Hestenes and Halloun (1995), minimising the probability of false positives can be challenging due to chance factors, as indicated by the mean of 10.46. Upon inspection, these items were found to have no inherent issues, and the higher percentages may be attributed to respondents potentially answering the Google Forms on their devices carelessly.

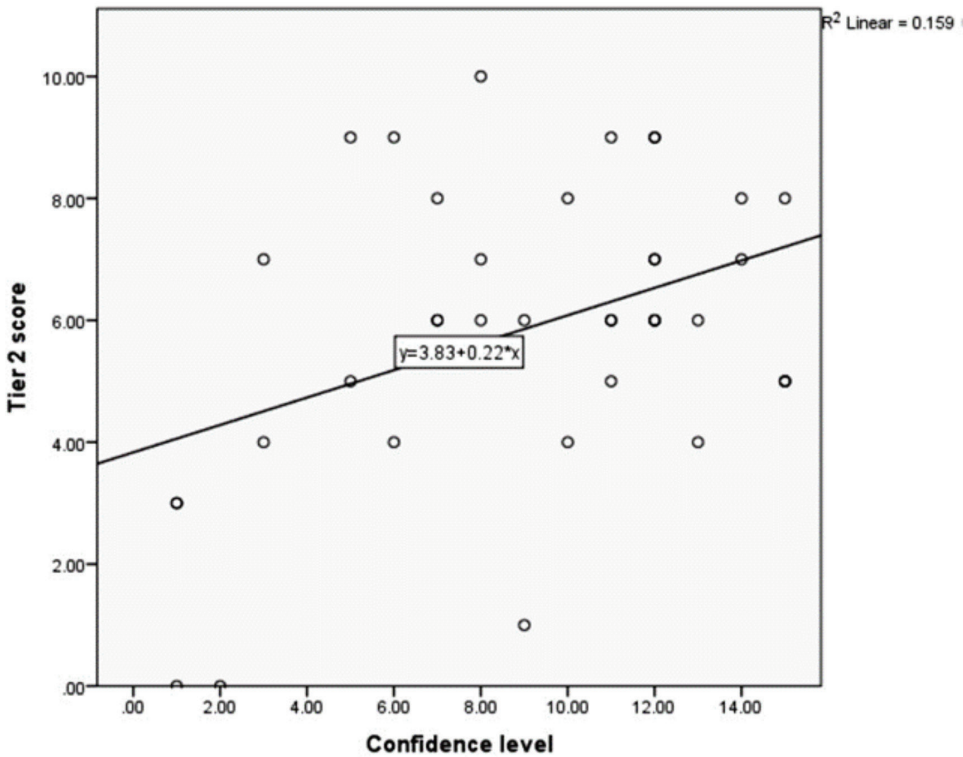


Figure 4: Scatter plots

In terms of false negatives, Items 2 (2.8%), 3 (6.4%), and 12 (1.8%) were identified, with a mean of 0.9 and an SD of 8.34. Hestenes and Halloun (1995) suggested that the probability of false negatives should be less than 10% for test items to be considered valid. Given that the false negative rate in this study was 0.9, it suggests that these items are indeed valid. Lastly, regarding the undergraduate students' lack of knowledge, Items 1 (47.3%, DNA Replication), 2 (51.4%, DNA Replication), 3 (52.3%, Sequence of events in central dogma), and 12 (40.4%, DNA Replication) exhibited percentages with a mean of 25 and an SD of 16.3. This outcome underscores one of the advantages of using a three-tier test as opposed to a conventional test.

Levels of Understanding of the Central Dogma of Molecular Biology

Table 4 shows the mean and standard deviation of the knowledge item scores regarding the central dogma of molecular biology.

The results indicate that undergraduate students have an overall mean score of 4.76 and a standard deviation of 2.31, reflecting a low understanding. This encompasses their understanding of the knowledge items related to the central dogma, their ability to provide explanations for the 1st tier, and their confidence in their answers for both the 1st and 2nd tiers. Aside from the identification of the misconceptions, it is also important to identify the level of understanding among undergraduate students regarding the central dogma of molecular biology. The findings highlight a significant concern, as they reveal that these students possess a low understanding of central dogma concepts. This is particularly problematic because various college-level subjects require a solid grasp of these concepts, such as cell biology and molecular biology.

Misconception about Central Dogma of Molecular Biology

Figure 5 shows the percentage of misconceptions in each item. Item 15: Translation (39%), Item 11: Transcription (18%), Item 7: Types of RNA (18%), Item 9: Transcription, Item 2: DNA Replication and Item 3: Sequence of events of the central dogma of molecular biology (15%) were identified to have the highest percentage of misconceptions in the topics of central dogma of

Table 3: Percentages of false positives, false negatives, and lack of knowledge of respondents

	Items (%)																
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**M**	**SD**
FP	22.9	4.6	4.6	1.8	3.7	4.6	13.8	1.8	15.6	3.7	11.9	7.3	12.8	29.4	18.3	10.46	1.7
FN	0.0	2.8	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.9	8.34
LK	47.7	51.4	52.3	4.6	8.3	9.2	26.6	8.3	28.4	16.5	23.9	40.4	10.1	24.8	26.6	25.0	16.3

Table 4: Mean and SD of the knowledge items regarding the central dogma of molecular biology

Statistics	N	M	SD
Respondents	109		
Items	15		
Highest possible score	15	4.76	2.31
Minimum score	0		
Maximum score	10		
Median	5		

molecular biology. These findings are indicative of the persistence of misconceptions in the central dogma of molecular biology topics from senior high school into college. This underscores the importance of actively identifying and addressing misconceptions to prevent their retention at higher educational levels.

Perceptions about Central Dogma of Molecular Biology

Table 5 shows the mean scores of the perception items from the CDMBQ. The results revealed that the PER1 item, "I remember the principles of the central dogma of molecular biology from my senior high school class," has a mean of 2.68, indicating disagreement with the statement, implying that students were unable to recall the principles of the central dogma of molecular biology taught to them in senior high school.

In addition, the PER2 item showed a mean of 2.33 in the question "The issues about the central dogma of molecular biology were not at all puzzling". This indicates that the central dogma's concepts are still unclear to students. In the PER3 item, "I quickly understood the concepts of the central dogma of molecular biology when it was discussed to us," the mean was 3.09, which is considered neutral. This

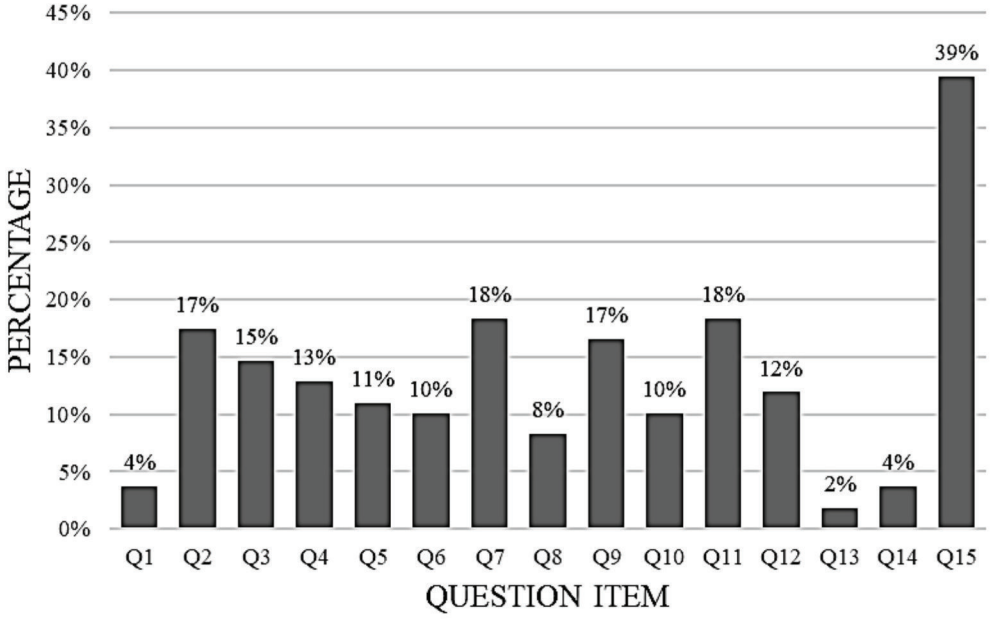


Figure 5: Percentage of misconceptions in the question items

Table 5: Mean, SD and interpretation of the perception Items of CDMBQ

Perception Items	N	Mean	SD	Interpretation
Per1	109	2.68	1.06	Disagree
Per2	109	2.33	1.06	Disagree
Per3	109	3.09	1.05	Neutral
Per4	109	3.98	1.05	Agree
Per5	109	3.13	1.37	Neutral

could have been due to their neutral feelings about the topic of the central dogma, which was difficult yet intriguing, as seen in their answers in the PER4 item, "The concepts of the central dogma of molecular biology are very intriguing," which had a mean of 3.98, indicating agreement. The mean for the PER5 question, "My science instructor has discussed the concepts of the central dogma of molecular biology very well," is 3.13, which is considered neutral. This neutrality might be due to cultural factors, as Filipino students tend to avoid criticising their teachers and prefer to remain neutral in their assessments.

Conclusion and Recommendation

The current study found that the CDMBQ was a valid and reliable tool for assessing undergraduate students' misconceptions in various biology-related courses. It has also been demonstrated that students have a low conceptual understanding of various aspects of the central dogma, notably DNA replication, translation, and the sequence of events in the central dogma. The CDMBQ also identified the specific areas in the central dogma of molecular biology that are prone to misconceptions, which are the sequence of events in the central dogma, the DNA replication process, types of RNA, and the translation process. The results of students' perceptions of learning the central dogma items reflected this, as their responses revealed that they do not remember the concepts of the central dogma and are confused about the lessons regarding the central dogma.

They also tended to express neutral opinions about how their science teachers taught them the central dogma, possibly due to cultural factors. Despite the difficulties students face in remembering and understanding central dogma concepts, they expressed strong interest in learning these concepts, which provides an opportunity for educators to address misconceptions and knowledge gaps. The results of the study have demonstrated the advantages of using a three-tiered test compared with a conventional one due to its ability to differentiate between topic items where students lack understanding and topics where misconceptions are prevalent. This differentiation can guide re-teaching efforts and help prevent the perpetuation of misconceptions in higher education.

Based on these findings, the researchers would like to advocate for the use of CDMBQ to evaluate misconceptions regarding the central dogma of molecular biology, This assessment can improve teacher instruction and assessment design. It can also be used to monitor students' understanding and to generate remediation activities to address such knowledge gaps, given its capacity to detect the percentage of knowledge gaps on item-by-item basis. The researchers would also encourage future researchers to explore adaptations of the three-tier test elements of the CDMBQ to evaluate the feasibility of reducing the number of test items to alleviate student anxiety when responding to the assessment.

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