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Content Analysis of Bioenergetics' Conceptual Presentation in Senior High School Biology Textbooks

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Abstract. Factors that bring about a low mastery level of bioenergetics, a core concept in biology, include relatively poor teaching-learning experience and low-quality textbooks, among others. To determine which textbook and teaching components have affected the low learning mastery of the topics in bioenergetics, the researchers analyzed the textbooks' quality of content, language, layout, and figures, and the teachers' experience, contentment, and challenges while teaching the topic, and effects to the learners. Using a sequential explanatory mixed method research design, ten (10) textbooks, and seven (7) teacher participants were purposively selected following a set of criteria. Descriptive and principal component analyses revealed that the textbooks' quality depends on two components: (1) competent and coherent visuals and content, and (2) consistency of style in the varied forms of assessment. Narrative analysis and Quasi-Statistics analysis revealed that teachers are not contented with the textbooks as they are inadequate to teach the subject matter. The lack of good learning materials, coupled with low competence to introduce the topics, resulted in the low mastery level of the learners. The researchers propose that periodic textbook assessment, retooling of teachers' skills, and deepening teachers' understanding are necessary to improve learners' performance in bioenergetics. Finally, this paper is instrumental in providing educators, resources and curriculum developers, and researchers a feasible and practical path to improve textbook quality and address pedagogical gaps.

Keywords: Bioenergetics, conceptual understanding, content analysis, teaching competence, textbook evaluation

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INTRODUCTION

Bioenergetics is a relatively new subfield recognized within biochemistry and cell biology and an active area of biological research (Yang et al., 2021). Bioenergetics is among the nationwide content standards of General Biology 1 and 2, one of the specialized courses under the STEM learning strand and the Academic career track of Senior High School in the Philippines (CHED K to 12 General Biology I and 2 Curriculum Guide, 2016). Understanding bioenergetics concepts such as photosynthesis, respiration, and how microorganisms convert energy, as well as mitochondrial metabolism in organisms, is critical for understanding global, societal, and environmental issues such as clean energy production (Insan et al., 2018; Yang, et al., 2021), food production (Grossman, 2019; Chow, 2019; Long, et al., 2019; Long, et al., 2015), medicine (Chávez et al., 2020 & Mayfield & Golden, 2015), bioremediation (Winardi et al., 2019 & 2020), and other ecological services (Janssen et al., 2014). As a result, it is getting more attention in the literature.

However, despite the popularity of bioenergetic concepts, it is emphasized in the literature that Senior High School students experience difficulties in learning the subject and that they have many relevant alternative conceptions, making them one of the least mastered topics in Biology (Salleh et al., 2021; Gungor, & Ozkan, 2017; Svandova, 2014). Results from various research revealed that a

variety of factors contribute to the poor performance of students, among these is the interdisciplinary nature of the concepts (Fauzi, et al., 2018; Ziegler & Montplaisir, 2014), abstract level (Etobro & Fabinu, 2017) inability to understand the actual mechanisms and its multi-faceted processes of energy exchange (Ozcan et al., 2014) and their incapacity to comprehend the subject's micro-and macro-level relationships (Kurt et al., 2013). Another factor preventing students from effectively learning bioenergetics is learning resources, mainly textbooks (Hadiprayitno et al., 2019).

High-quality science textbooks are a significant catalyst for students and teachers to improve their teaching and learning processes (Devetak & Vogrinc, 2013; Zulfah & Aznam, 2018). It can also develop a deep understanding of science concepts, and provide extensive explanations in teaching the topics, and this fundamental function of the textbook has long been recognized by many researchers (Vojíř, & Rusek, 2019; McDonald, 2016). Textbooks must have these essential elements: textual and visual (pictorial) to be regarded as high-quality (Wijekumar, et al., 2021 & Yazdanmehr, et al., 2014). When these two modes of information complement each other, students can build a better conceptual understanding of scientific phenomena. Although many studies have focused on science textbook graphics and textual utilization, the Bioenergetics textbook's visual representations, coherence, clarity of thought, grammar, and syntax deserve further attention. For these reasons, the most widely used biology textbooks in Senior High Schools (SHS) in the Philippines must undergo critical analysis to assess how these textbooks align with the principles and standards of the SHS Science curriculum. Although several studies have conducted content analysis on science textbooks in general (McDonald, 2016), and biology textbooks in particular, however, they lack investigation on the textbooks' quality of content, language, layout, and figures of science textbooks. Moreover, the researchers have not yet encountered a published paper evaluating the content of Bioenergetics textbooks.

Furthermore, teachers rely on the textbook to decide the content of instruction and how to deliver the information, especially when they are teaching beyond their field of expertise (Mcdonald, 2016). Researchers also added that teachers spend more than half of their classroom time utilizing this learning material, and they base most of their instructional decisions on the textbook. As a result, the content's quality and correctness are critical to its educational effectiveness, and inadequacies and inconsistencies in science knowledge offered in textbooks may affect students' understanding of scientific concepts (Yun et al., 2015). Thus, as facilitators of learning, studies regarding teachers' awareness and evaluation of the flaws of the textbook should be given much attention. However, studies focusing on teachers' experiences utilizing science textbooks, particularly on the contentment of the textbook, challenges faced, and effects on the learners, are limited.

Thus, this study aims to shed light on the research gaps mentioned and intends to investigate and determine the factors affecting the underperformance of Bioenergetics of Senior High School learners in the Textbooks used and in the teachers' experiences. Specifically, the investigation analyzed the textbooks' (1) content quality, (2) language appropriateness, and (3) layout and figures quality. This paper also explores the experiences of the teachers in using the textbooks in teaching Bioenergetics, focusing on their (1) contentment with the textbook, (2) challenges faced, and (3) effects on the learners. This paper is instrumental in supporting and providing educators with a comprehensive understanding of the challenges faced by learners, which informs targeted interventions and enhancements. Investigating both textbook and teachers' experiences enables resource and curriculum developers to make informed decisions, as well as provide a feasible and practical path to improve textbook quality, enhance content delivery, and address pedagogical gaps through science educators' training and professional development.

METHODS

Research Design

This study utilized the Sequential Explanatory Mixed Method Research Design. This design is appropriate for this study as it made use the qualitative data and analysis to provide meaning to the quantitative information and evidence. Content Analysis Research Method (Bengtsson, 2016) which provides an objective and systematic evaluation of documents, was employed for the quantitative data gathering and analysis. The documents that were evaluated are the Senior High School Textbooks on General

Biology I in the Visayas and Mindanao Region. In the case of qualitative data gathering and analysis, Narrative Research Design was utilized. This design provides valid inferences and generates meaning from the narratives of the teacher-participants to deepen the understanding of the analysis done on the textbooks.

Quantitative Data Collection and Analysis

Selection of Textbooks

The quantitative data were collected from the General Biology 1 Textbooks utilized by the Senior High School teachers in teaching Biology. The textbooks were selected from those that are often used in Mindanao and Visayas. The criteria in the selection of textbooks are as follows: The textbook is (1) used as the primary reference material in both public and private schools, (2) authored by either Filipino or Foreign authors and (3) published within the year of 2010-2020.

Inclusive Topics

The selected textbooks were collected by borrowing copies from the teachers who have used them in teaching. These are evaluated on the Bioenergetic topics that are based on the Learning Competencies for Senior High School from the Department of Education (DepEd), Philippines. These topics are (1) ATP-ADP Cycles, (2) Photosynthesis, and (3) Cellular Respirations.

Research Tool

The adapted and modified Department of Education evaluation tool was utilized in the evaluation of the following parameters: (1) content quality, (2) language quality, and (3) layout and figures quality of the General Biology Textbooks.

Evaluation Procedure

The textbooks are initially evaluated by one, the same, researcher to ensure that there is no inconsistency and objectivity is maintained during the process. Then the evaluation results and copies of the textbooks were sent to the other researchers for check and balance. It is ensured that the other researchers were able to review the textbooks. The comments and suggestions on the initial evaluation were synthesized to reach the final evaluation of the textbooks.

Data Analysis

The results of the evaluation of the textbooks were processed by using Descriptive Statistical Analysis and Principal Component Analysis. Under descriptive analysis, the mean scores of the three criteria (content, language, layout, and figures) were calculated to determine the average quality of the textbook in each criterion. The mean of each criterion was also placed into the descriptive analysis to determine the overall quality of the textbooks. Meanwhile, principal component analysis was utilized on the scores of the sub-criteria of the main criteria to identify the primary components that serve as the determining factor in the quality of textbooks.

Qualitative Data Collection and Analysis

Research Participants

Teachers were selected through a purposive sampling method. These teachers were the users of the textbooks that were selected in the evaluation process using the following criteria: (1) teaching general biology for 4 years or more, (2) using at least one of the selected textbooks, and (3) teaching in public or private schools. The emphasis on the number of years teaching is an assurance that the teacher has enough teaching experience and in the utilization of the textbook. Out of the 10 biology teachers from Visayas and Mindanao who were invited, only seven (7) were included in the qualitative interview as it already reached the data saturation point and no new themes emerged.

Research Tool

To gather the experiences of the teachers on their experience in teaching the topics of Bioenergetics and usage of the textbooks, a researcher-made interview question guide was crafted and also it was validated and authenticated by an expert. The interview guide probes (1) the usefulness of the textbook in the teaching and learning process; (2) challenges that they have experienced; (3) how they have addressed the challenges; and (4) their recommendations and suggestions on how to improve the textbooks.

Data Gathering Procedures and Ethical Considerations

Before the conduct of the study, a certificate from Cebu Normal University's Research Ethics Committee was obtained. Following acceptance, the researchers delivered an invitation, a consent form indicating voluntary participation, and the option to withdraw from the study at any time. A research outline, including a copy of the participant's rights and confidentiality protection, was also provided. All of these were delivered to the teacher participants via email. To ensure confidentiality and anonymity, each participant was given a code.

A certificate from the Research Ethics Committee of Cebu Normal University was secured before the conduct of the study. After the approval, the researchers sent an invitation, a

consent form that indicates voluntary participation, and a provision to withdraw from the study at any time. A research outline with a copy of the participant's rights and confidentiality protection was also included. All these were sent to the teacher participants via email. For confidentiality and anonymity, the hard copies of the data collected from teachers were maintained in secured filing cabinets, while the soft copies were saved on password-protected PCs. A code was also used to assign to each participant before conducting an interview. Furthermore, interview questions were sent in advance for them to be able to prepare, and were asked to set the date and time so that the interview would be convenient for them. Then, semi-structured interviews were conducted through video conferencing using online platforms that lasted around 45 to 60 minutes. Recordings and taking notes during the interviews were done with the teacher participants' approval. Responses from seven (7) participants reached the saturation point, and no new themes emerged.

Data Analysis

The teachers' responses were analyzed through Narrative Analysis coupled with Quasi-Statistics Analysis. In the process of Narrative Analysis, responses were transcribed and coded. In the process of coding, the number of participants who provided narratives of the same explicit and implicit meanings was accounted for through the process of Quasi-Statistics Analysis. The accounted number of participants is reflected in the codes presented in the results and discussion which are then followed by vignettes. Then, the codes are grouped into themes which are also categorized according to their directed meaning. The themes are then correlated to the quantitative results to provide insights and deeper analysis.

RESULTS & DISCUSSIONS

Textbook Quality

Quantitative results

The ten (10) textbooks were analyzed based on the quality of Bioenergetics content, language presentation, and layout and figures representation of the concepts. The results below show the average assessment of the identified ten (10) textbooks (Table 2).

Table 2. The Average Evaluation Summary of the Ten Identified Textbooks

Evaluation Criteria	Average Score	Interpretation
Content	0.64	Average Quality
Language	0.86	High Quality
Lay-out & Figures	0.61	Average Quality
Average	0.70	High Quality

Legend: 0.00 – 0.33: Low Quality; 0.34 – 0.67: Average Quality; 0.68 – 1.00: High Quality

The content's average quality of the textbooks stems from the suitability of the provided concept. In the Filipino-authored textbooks, the provided contents were indeed understandable however, it lacked the necessary preliminary concepts to clearly understand the bioenergetics concept. It can be observed that pre-requisite topics on redox reactions and energy transformation were not explained and applied to biological processes. Most of the books have merely defined and discussed these processes. Several steps and procedures in photosynthesis and cellular respiration were delimited in the description and explanation of the occurrence of these processes. The omission of a detailed explanation confuses the learners in the energy transformation, movement of electrons, and the changes happening to the substances. Moreover, eight out of 10 books are not updated in terms of the number of ATP produced in the different biological processes

Furthermore, the insufficiency of the figure affects the understanding of the concepts as well (Devetak and Vogrinc, 2013). Figures presented among eight (8) reviewed textbooks are insufficient in terms of labels and detailed processes. Most of them have shown only the general name of the process in the figure and do not show the transformation of substances, transfer of electrons, and aid of enzymes. The biological processes are abstract and cannot be seen readily with limited instruments and apparatus and most teachers and learners would rely on diagrams and figures to understand them. Thus, the lack of detailed figures affects how teachers and learners would understand the topic. The figures are placed on a different page or spread from the description and explanation. The processes are also not broken down into parts to provide clearer references for the learners to compare with the explanation. This lack of connection of the text to the figure proves to be

difficult to learn association as you will have to flip to another page to see the illustration of how the process takes place.

This initial analysis of the textbooks' components is consistent with the results of the Principal Component Analysis. The tables below show the results of the analysis with table 3 demonstrating the number of principal components and table 4 displaying the contents of each component.

Table 3. The results of the analysis of textbooks' components demonstrating the number of principal components

Component	Total	% of variance	Accumulated %
1	4.703	67.192	67.192
2	1.348	19.251	86.442
3	0.402	5.744	92.186
4	0.24	3.425	95.611
5	0.207	2.96	98.571
6	0.071	1.009	99.58
7	0.029	0.42	100

Table 4. The contents of each textbook's component

	Components	
	1	2
Instructional Design and Organization of Material	0.773	-0.483
Instructional Quality	0.916	0.047
Assessment	0.651	-0.722
Coherence and Clarity of Thought	0.858	-0.092
Consistency in Style	0.664	0.688
Book Lay-out and Design	0.925	0.211
Visuals	0.901	0.253

Two (2) principal components greatly affect the quality of the textbooks in terms of Bioenergetics. The primary component derived from the four (4) factors identified in Table 4 is "Competent and Coherent Visuals and Content". This suggests that Bioenergetics textbooks should provide clear, correct, and complete content and visual representations of the biological process as these are the key factors that provide learning mastery (Perilli, 2019; As & Parimalafathima, 2019). However, it should also be taken into consideration that there is consistency between content and figures (Devetak and Vogrinc, 2013). As explained above, it is unfortunate that these are the lacking components of most of the Filipino and Foreign authored textbooks that were reviewed.

The secondary component derived from two factors as shown in Table 4 is "Consistency in Style in the Varied Forms of Assessment". The provision of several diverse assessments is also an integral process as these activities provide a review and evaluation of the learner's understanding of the topic (Osborne, 2015; Edwards, 2013). Bioenergetics is a multi-layered topic as such it also requires a multi-layered assessment (McLester, 2016) that builds upon the understanding of the overlapping concepts therein. Although there is variety and an increase in the required level of understanding in Filipino-authored textbooks, the assessments and activities do not build up the learning from simple to more complex ones. They are not linearly aligned with each other but instead have their focus and purposes. On the Foreign-authored textbooks, assessments and activities are too few in comparison to the number of contents it has presented. Hence, only a few contents are reviewed and checked for understanding.

Qualitative Results

The narratives of the teachers support and explain further the results of the quantitative results. The table below summarizes the qualitative themes on textbook quality.

Table 5. Themes on Textbook Quality

Superordinate Themes	Subthemes
Superordinate theme 1: Textbook Quality	Subtheme 1: Insufficient Content. Subtheme 2: Lack of Visual Representation and Activities.

The teachers have expressed that their textbooks lack content. Subtheme 1: Insufficient Content explains the lack of helpful information that the textbooks have. Although they can say that the textbooks were helpful, teachers (7 out of 7) have admitted that they have limited detailed explanations to provide a clear understanding of the topic. Teachers say, "*The books are not enough*" (P4) because the "*details were not enough*" (P6). The "*details of some topics in bioenergetics are not complete for further elaboration and explanation*" (P1 & P7). "*The examples provided are broad and complex"* (P3), and there is "*difficulty in the unpacking of sub-topics of the learning competencies*" (P6).

Teachers were also honest in evaluating that

the textbooks they are using indeed require better figures and visual representation as well as activities. This is expressed in subtheme 2: Lack of Visual Representation and Activities. Teachers (7 out 7) have identified that another challenge with the teaching of bioenergetics is the limited number of visual representations and learning activities that they can use for teaching. Teachers mentioned that "*The books miss to put labels on illustrations depicting the processes of cellular respiration and photosynthesis and some pictures are small and blurred. That's why illustrations in the book do not help explain the process of Glycolysis, Krebs Cycle and the Electron Transport Chain.*" (P1, P3, P4, P5) Also, "*there is no caption and explanations on the illustrations presented. Some concepts need illustration but unfortunately, the authors miss putting an image on it.*" (P2, P6, P7)

Teaching Quality

Qualitative Results

The underperformance of students in Bioenergetics is not only attributed to the quality of the textbooks but also to the teaching quality and experiences provided by the teachers. The table below summarizes the qualitative themes on Teaching Quality.

Table 6. The Qualitative Themes on the Quality of Teaching and Experiences Provided by Teachers

Superordinate Themes	Subthemes
Superordinate theme 2: Teaching Quality	Subtheme 3: Insufficient Content Mastery
	Subtheme 4: Lack of Alternative Teaching Strategies & References

The narratives of the teachers revealed that more than the textbooks, they are responsible for the results of the student's performance. Subtheme 3: Insufficient Content Mastery suggests that the lack of the capability of the teachers to teach the lessons in Bioenergetics affects the quality of learning. The teachers' regular bursts of laughter and side glances whenever asked about their difficulty imply that they are having a hard time teaching the topics. More than just the lack of reference materials, their mastery of the content is something to be developed further. In fact, teachers *(7 out of 7)* have admitted that they are only proficient and confident in teaching some of the topics of bioenergetics. The common topics that they are confident to teach are *Photosynthesis* (P1, P3, P4, P5, P6, and P7), *Cellular Respiration* (P1 and P2), and *Energy Transfer* (P3).

Their confidence to teach these topics comes from their *familiarity* (P1 & P7), *the number of reference materials there are for the topic* (P1 & P2), their *deep understanding of the topic* (P3), and *the number of times that they have taught the topic* (P4 & P5). The teachers *(3 out of 7)* have reasoned out that their inability to confidently teach the other topics in Bioenergetics is coming from their limited understanding of it. Some teachers *(3 out of 7)* have difficulty understanding the topic due to the complexity of the processes and concepts that are involved and the lack of reference materials

Although admittedly there is incompetence in teaching the topics on Bioenergetics, the blame should not solely lie on the teachers themselves as there are several factors that affect competence. One of these factors is their pre-service learning and training (Tambunan, 2014). As such, higher education professors, mentors, and coaches of science student teachers must provide rigorous training not only on the pedagogy but also on the mastery of the content. Furthermore, intensive training should be provided by the Department of Education for the in-service teachers.

Nevertheless, the effort of the teachers to find relevant resources and to resolve their dilemmas and problems on the lack of resources and their lack of content mastery should also be taken into consideration. Amidst difficulties, the teachers look for ways in which they can fill in the missing parts or the gaps in their teaching as expressed in subtheme 4: Lack of Alternative Teaching Strategies & References. The challenges that the teachers have faced in teaching the topics of Bioenergetics have encouraged them (3 out of 7) to develop and adapt teaching and learning strategies from other sources. They said, "*Having these challenges affects me in my teaching in the sense that it can make me feel stressed thinking that I could not explain and elaborate more on the topics that I will be discussing. It made me reflect and think even more about how I could come up with a good and effective instructional delivery to my students."* (P1, P3, P5)

Unfortunately, the available teaching-learning materials are still insufficient. Teachers (7 out of 7) say *"Textbooks are meant to help me discuss topics effectively, but I am saddened*

because the provided reference does not deliver the promise. I still need to read a lot and spend more time in the preparation of the lesson which is supposedly provided in the textbook." (P7)

Since the Philippine Textbooks on General Biology were published last 2017 and are still in their 1st Edition, this implies that the books need more review and evaluation. The textbooks that were utilized in the teaching of Bioenergetics have some gaps in terms of content, layout, and figures. The researchers' evaluation is confirmed by the principal component analysis and is further supported by the teachers' experiences. Consequently, these gaps in the textbooks have affected the teaching quality. These have become the sources of their challenges as they lack competent learning resources that serve as their reference for teaching and learning.

Effects on Learners

Qualitative Results

The interplay of textbook and teaching qualities on Bioenergetics affects the learning quality of the learners. The table below summarizes the observations of the teachers on the learners.

Table 7. The Qualitative Themes on the Quality of the Learning Materials that Affect the Learner's Quality of Learning

Superordinate Themes	Subthemes
Superordinate theme 3: Learning Quality	Subtheme 5: Disengagement Subtheme 6: Insufficient Learning Mastery

The quality of the learning material and instruction has affected the learners. The first effect is on the psycho-emotional aspect of the learners as expressed in subtheme 5: Disengagement. Teachers *(3 out of 7)* have noticed that with the quality of materials and instructions that they have provided to the learners, interest in learning bioenergetics has dwindled. Engagement is an important factor in learning, and teachers have understood that when learners are not routinely and actively engaged in learning, content mastery is negatively affected. Teachers mentioned that "*When teachers are challenged in delivering the topic, for sure students will suffer. Tendencies are students will not be interested in the lessons and learning will also become dismal."* (P4, P5, & P7)

The second effect on the learners is on the cognitive aspect as described in subtheme 6: Insufficient Learning Mastery. The lack of appropriate and sufficient learning materials that help guide the learners in the comprehension of bioenergetics is one of the factors that have been identified by the teachers *(4 out of 7)*. However, the insufficiency of their lack of understanding in the delivery of the lesson cannot be ruled out as well as a contributory factor in the low level of understanding and achievement. Teachers mentioned that "*These challenges affect the student's learning especially in the retention and mastery of the lesson and on the student's evaluation process. Not being able to visualize the processes and complete reliance on the teachers in bioenergetics would make the students hard to stay motivated and would make them feel bored leading to unsatisfactory results on their assessment and evaluation process."* (P1, P2, P3, & P4)

CONCLUSION

Based on the results it can be concluded that learning materials and instructions are the primary factors that affect learning. The underperformance of Senior High School learners in Bioenergetics is attributed to the quality of textbooks used and the teaching-learning experiences provided. In the mastery of the topics of Bioenergetics, much is required from the standards of content and visual presentations of textbooks and the content and pedagogical expertise of the teachers to provide suitable learning experiences that engage and develop mastery among learners. Moreover, teachers should continue to enhance and deepen their understanding of the subject matter, innovate strategies to further improve the transfer of learning, and craft learning materials that are suited to the varied teaching and learning styles. It should also be highlighted that training both with the pre-service and in-service teachers be further strengthened.

Based on the crucial factors that have been identified in this study, it is suggested that further studies on the implementation and actual teaching of Bioenergetics in Senior High School Students be conducted to identify factors in the teaching process that greatly affect the mastery of learning. Furthermore, it is suggested that learners' perceptions be gathered to deepen the understanding of the factors found in this study.

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