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Exploring the Factors Affecting the Integration of Mathematical Skills into Biology Learning in Copperbelt Secondary Schools of Zambia

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Abstract 21st century biology is becoming increasingly quantitative, requiring students to master mathematical knowledge for them to fully understand and apply the new emerging biological concepts and skills for socio-economic development. This study, therefore, aimed to determine the factors affecting the integration of mathematical skills into biology curricula at secondary school level in Zambia. Primary data was collected using a quantitative biology assessment test for biology class pupils and survey questionnaires for both biology teachers and pupils. Secondary data was obtained from past biology examinations papers of the Zambia General Certificate of Secondary Education/O-level (GCSE) and the Cambridge University International General Certificate of Secondary Education (IGCSE) for the years 2010 – 2016. The study sample was 140 biology class students and 16 biology teachers selected from 8 secondary schools in the Copperbelt province of Zambia. Statistical analyses using descriptive statistics, one-way ANOVA and factor analysis were conducted using SPSS and Excel. The results of this study revealed a mean pass rate in the quantitative biology test of merely 14.3%, with the lowest mean score (6%) obtained for questions in the higher order cognitive levels of Bloom's taxonomy. The coverage of mathematics related questions in the national biology examinations was low at 7.1% and 18.9% for GCSE and IGCSE, respectively. Overall the pupils had inadequate skills for tackling quantitative biology questions. The contributing factors for this situation included the lack of quantitative competencies amongst biology teachers and the unavailability of appropriate textbooks to guide teachers and students. The biology syllabi and assessment requirements do not compel teachers to teach mathematical biology. Consequently, students exhibited phobia and a negative attitude towards quantitative biology. Overall, Zambia requires a new educational policy framework that should drive the integration of mathematics and biology throughout the Zambian educational system.

Keywords: *students, mathematics, biology, integration, teachers*

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1. Introduction

Biology is the study of the complexity of life and the attendant factors that shape life itself. In essence, one would expect biology to embrace the entire sciences to be able to fully understand and explain the intricacies and complexities of the diversity of life forms. However, historically biology has distanced itself from such sciences as physics and chemistry by choosing a path of qualitative descriptions in its formulation of life as an academic discipline. On the other hand, by the turn of the 20th century, biology found itself confronted with a plethora of societal challenges in such sectors as medicine, agriculture and industry, whose solutions required the application of interdisciplinary approaches and quantitative skills. Consequently, biological sciences have evolved into disciplines that require strong and deep interphase with physics, chemistry and mathematics. Examples of such disciplines include bioprocess engineering which links biological sciences with chemical and mechanical engineering, while bioinformatics integrates the power of computers, mathematical algorithms, and statistics with concepts in the life sciences to solve biological problems. Synthetic biology is also opening up new frontiers in the design and engineering of biologically based parts, including the redesigning of existing natural biological systems. Additionally, disciplines such as systems biology and computational biology involve the application of mathematical concepts and models to study biological processes at molecular, intercellular and physiological levels. It is, therefore, evident that 21st century biology is becoming increasingly quantitative, requiring students to master mathematical knowledge for them to fully understand and apply the new emerging biological concepts and skills for socio-economic development. Today, the use of physical principles and mathematics in the life sciences – is widespread and generally accepted as a powerful and important tool. It also marks an era in which excess quantitative data of biological origin is available and there is a sense that biological complexity can be tackled if the right mathematical framework can be found [1].

While the necessity for biologists to deepen their mathematical knowledge and skills is evident, the appropriate pedagogical strategies for achieving this are still debatable. The conventional practice, in both the developed and developing countries, is to teach biology and mathematics independently of each other. This parallel approach to knowledge/skills generation and delivery often hinders the understanding of how each discipline informs and influences the other. Students have difficulty when applying their knowledge from one course to another and are often unable to synthesize their knowledge into a cohesive and productive framework [2].

Quantitative competencies are critical for analyzing biological data. Biologists have exhibited deficiencies in handling and interpreting statistical analyses in their scientific publications (Nieuwenhuis et al., [3]). The current pedagogical practices, therefore, deprives biologists of quantitative competencies that are essential for comprehending, researching, interpreting and communicating complex biological phenomena and concepts.

In Zambia mathematics is a compulsory subject at primary and secondary school levels, while biology is elective. However, at tertiary level, the continued learning of biology and mathematics becomes dependent upon the programme to which the student has been admitted .In the case of undergraduate programs in the Copperbelt University, biology students in the School of Natural Sciences learn mathematics as a compulsory course in the first year and not in the subsequent years. Moreover, mathematics is taught as a separate course without any references to linkages with biological concepts and processes.

There are various reasons and factors as to why academic programmes in biological sciences pay little attention to the need to strengthen quantitative competencies of students, through systematic exposure of biology students to mathematics. Gross, et al., [4]; have noted the prevalence of feelings of dislike towards quantitative subjects or “math anxiety” among students who choose to major in biology. It can be assumed that teachers and lecturers of biology are also victims of mathematics anxiety as they themselves are products of the same education system. They, therefore, formulate biology syllabi and curricula that are devoid of mathematical content. Others (Hillel, et al., [5]) have cited institutional and professional obstacles as barriers to integration of mathematical skills and tools into biology syllabi, whereby the number of credits that are needed to satisfy a major or professional stipulation may restrict the number of courses that students take outside of biology majors.

It is evident that quantitative training of modern biology students demands full integration between biology and mathematics at all levels of biology education. This study, therefore, aimed to determine the factors hindering the integration of mathematical skills into biology curricula at secondary school level in Zambia. The immediate objectives were thus as follows:

a) To determine the ability of students to articulate biology-related mathematics questions.

b) To explore the level of mathematics content in the questions presented to pupils in the final national biology grade12 examination.

c) To investigate the factors affecting the teaching and learning of mathematics in biology in secondary schools

2. Methodology

This study was centered on grade 12 secondary school pupils and biology teachers. In the Zambian context these are students who have done seven years of primary education and were now in their fifth and final year of secondary education. These students were preparing for their final year national examinations which would qualify them to enter tertiary education. Grade 12 students were chosen purposively because they had already completed the biology secondary syllabus. Consequently this study targeted grade 12 students for insights on the quantitative training of biologists in Zambia.

2.1. Study Sample

The targeted population for this study was selected from eight secondary schools in Copperbelt province of Zambia. A total of 140 biology class pupils comprising of 80 males and 60 females and 16 biology teachers from the same schools were chosen. The grade 12 students preparing for the 2016O level examination were selected purposely, because they have already covered the syllabus and it was important to check whether they were adequately trained for basic quantitative reasoning in biology to receive the higher level quantitative skills. Simple random sampling was used to select the students in this study to have equal chance of participation [6] and the teachers were selected purposively.

2.2. Data Collection Procedures

Primary data was collected using a performance assessment test for pupils and survey questionnaires for teachers and pupils. The test was intended to assess the ability of students to apply mathematical skills in biological contexts. A test paper was thus designed comprising of 24 questions aligned to Blooms taxonomy, i.e., reflecting the various levels of cognitive skills and administered to the pupils.

Survey questionnaire instrument was used, to provide information on the factors affecting the integration of mathematics in biology. The questionnaire was structured with5-point Likert-scale responses which focused on themes pertaining to the teaching and learning of integrated biology and mathematics in Zambian classrooms, the roles of syllabi and text books in embedding mathematics into biology disciplines.

Secondary data about the content of mathematics questions in biology examinations were obtained from the

Zambian General Certificate of Secondary Education/O-level (GCSE) and International General Certificate of Secondary Education (IGCSE) Cambridge papers for the years 2010 – 2016 and analyzed. These papers were used in this study because they originated from examination bodies which are currently recognized by the Zambian government and all secondary school biology students are required to sit for either of these papers in their final year.

2.3. Data Analysis

The collected primary and secondary data were subjected to statistical analyses using descriptive statistics, one-way ANOVA and factor analysis with principal component analysis using SPSS (Vs. 21) and Excel.

3. Results and Discussions

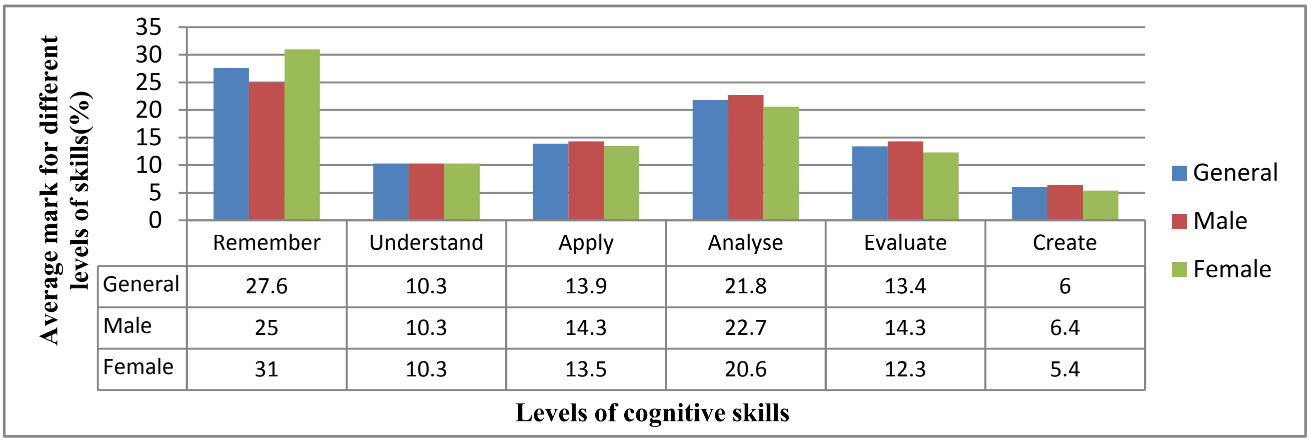
The first objective of this study was to determine the ability of students to articulate biology-based mathematics questions. This was achieved by presenting a performance assessment test paper on quantitative biology to biology class students at the eight secondary schools. The intention was to determine whether secondary school students had achieved sufficient quantitative skills to be able to apply mathematics into biology contexts. The test in the context of this study can be referred to as "quantitative biology test".

The test questions were disaggregated into categories of Bloom's taxonomy cognitive skill levels of remembering, understanding, applying, analyzing, evaluating and creating. The test scores from all the eight schools were pooled and the results are presented in Figure 1. The overall mean performance score in the quantitative biology test, irrespective of the cognitive levels, of all the students across the entire eight secondary schools was14.3%.The mean scores for females and males were 13.8%and 14.6%, respectively.

It is evident that the performance of students in all the six cognitive skill levels was generally poor. However, within these low scores, the performance at the different cognitive skill levels was not similar. The highest mean score was in the remembering (27.6%) category followed by the analyzing skill level. The students exhibited their lowest performance in questions under the "creating" category (6%), while the cognitive levels of understanding, applying and evaluating had relatively medium scores (Figure 1).

Overall, these results are indicative of the fact that secondary school students failed to apply their mathematical skills and knowledge into life-science contexts. These results are in conformity with the findings of Susan et al., [7] who observed that when biology and mathematics were taught as separate subjects, students exhibited the inability to transfer their mathematics skills to biological problems. This is also supported by the fact that in this study the students scored very lowly in the higher-order thinking skills of evaluate and create which are necessary for making connections and generating new ideas and concepts with regard to biology and mathematics.

This study has also shown that female students scored better than males in "remembering" but males exceeded females in all the other cognitive skill levels (Figure 1). However, a one way ANOVA ($p \leq 0.05$) showed that there was no significant difference between males and females in the scores at the various cognitive skill levels. The consequence of this is that secondary school students, irrespective of gender, join tertiary education institutions ill-equipped for the quantitative aspects of biology education.



	Remember	Understand	Apply	Analyse	Evaluate	Create
General	27.6	10.3	13.9	21.8	13.4	6
Male	25	10.3	14.3	22.7	14.3	6.4
Female	31	10.3	13.5	20.6	12.3	5.4

Figure 1. Performance scores of students in different cognitive skill levels

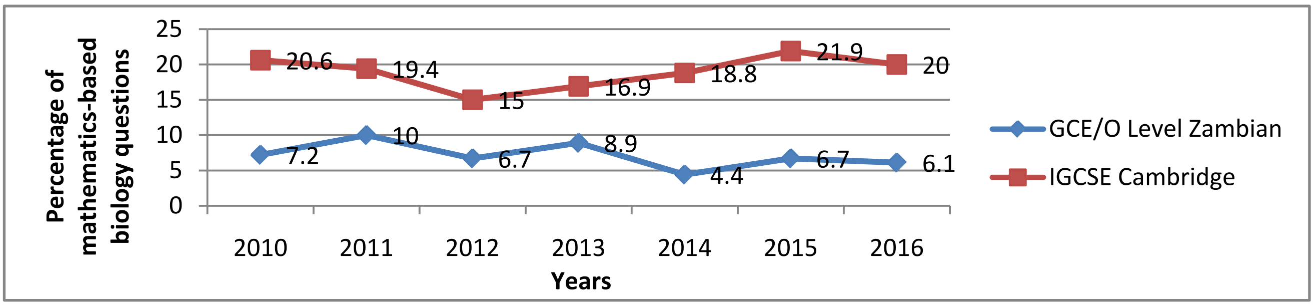


Figure 2. Comparison of the extent of mathematics-based biology questions in the GCSE /O Level Zambian and IGCSE Cambridge O level examinations

This study further explored the level of mathematics content in the questions presented to pupils in the final national biology grade 12 examination. The assumption was that the questions in the examinations should reflect the biology curriculum intent for mathematical related biology. This was thus an indirect way of finding out whether the Zambian biology curriculum compelled teachers to teach the quantitative aspects of biology. The findings are presented in Figure 2.

The mean percentage of mathematics-based questions over the seven year period (2010-2016) for the Zambian biology examination papers was 7.1%, while that for Cambridge examinations was 18.9%. The range for the Zambian examinations was from 4.4 to 10% and Cambridge was from 15 to 21.9%.It is evident that the Zambian biology teacher is not compelled to integrate mathematical skills in biology teaching as the students can still excel in the biology examinations without it.

Content analysis of both the Zambian and Cambridge (UK) biology syllabi objectives revealed that the latter was explicit on integrating mathematical skills and techniques, requiring 30% of overall qualification to be in handling information and problem solving (Cambridge International Examination, [8]). The Zambian syllabus was silent on these features (Curriculum Development Centre, [9]). These findings suggest that Zambian secondary school students are less exposed to the application of mathematics in biology as compared to their international counterparts. This implies that Zambian students join the tertiary institutions with a poor background in quantitative biology.

This study also sought to determine the pedagogical factors influencing the learning of quantitative biology in secondary schools. The data from the questionnaire survey of biology class students were subjected to factor analysis with principal component analysis. The results of the analysis are presented in Table 1 that shows five factors (components) as being important for our study. These five factors accounted for 64% of the total variance.

The first factor pointed to the inability of biology teachers to apply mathematics in the teaching of biology, which was characterized by such attributes as teachers never providing skills on handling mathematical biology questions to students, teachers never making connections between biology and mathematics, teachers not giving importance to quantitative biology questions, teachers not knowing how to connect mathematics and biology. Lastly, biology text books not having mathematical biology content. This suggests that biology teachers in secondary schools lack the capacity to teach quantitative biology and the appropriate text books are not available.

The second factor was mathematics anxiety or phobia on the part of students, with attributes of students fearing to answer biology-based mathematics questions and lacking confidence towards quantitative biology. Lebata & Mudau [10] also found that students exhibited lack of confidence towards mathematical biology. The third factor validates factor one above with students not practicing mathematical biology questions and not being exposed to skills in mathematical biology. The fourth factor was aligned with the attribute of students forgetting the mathematics they learnt in earlier grades and having a negative attitude towards mathematics. These results are in conformity with the findings of Mbugua,et al., [11]. The fifth factor was that students expressed their dislike for mathematical biology questions because they were difficult and hence they avoided answering them.

Overall, these results show that the pupils in the Copperbelt Province of Zambia are not as yet learning quantitative biology because teachers lack appropriate training and do not have access to quantitative biology textbooks. Accordingly, the learning of biology in secondary schools in Zambia is currently dominated by the traditional descriptive approaches of pedagogy.

Table 1. Factors Affecting the Teaching and Learning of Mathematics in Biology in Secondary Schools

Variables	Components				
	1	2	3	4	5
I am not given enough mathematical biology questions to practice			.802		
I have forgotten the mathematics which we have learned.				.692	
I fear mathematics which contribute to the poor performance in quantitative biology questions		.689			
I have lack of confidence which contribute to the poor performance in quantitative biology questions		.741			
Biology teachers never gave us experience on handling quantitative biology questions	.699		.506		
Biology teachers never make connections between mathematics and biology during teaching	.847				
Biology teachers do not give much importance for quantitative biology questions	.771				
Biology teachers do not know how to connect mathematics and biology	.559				
I do not like mathematical biology questions because, I find it difficult to get it correct, and hence avoid to answer					.826
Text books do not have mathematical biology questions	.605				
I have negative attitude towards mathematics				.824	

Rotated Component Matrix (Extraction Method: Principal Component Analysis).

Table 2. Mean Responses of Teachers on Integration of Mathematics in Biology During Their Teaching

Responses from teachers	SA(1)	A(2)	NS(3)	D (4)	SD(5)	Mean of responses
I don't include mathematical related biology questions in biology teaching		2		14		4
I don't teach mathematical biology questions because I don't like mathematics			1	7	8	4.4
I don't teach mathematical biology questions because I have an attitude that biology and mathematics have nothing in common		1		9	6	3.5
The syllabus does not show me the mathematical biology to be taught		9	1	5	1	2.9
The text books for biology do not show mathematical biology to be used when teaching at secondary school.		4		11	1	3.8

Key: SA= Strongly Agree, A= Agree, NS=Not Sure, D=Disagree, SD=Strongly Disagree.

The questionnaire for teachers was used to collect information on integration of mathematics in biology during their teaching. The results of the teachers' responses are shown in Table 2.

The responses of the teachers indicate that the biology syllabus does not show the application of mathematics in biological concepts (Table 2), which is in line with the pupils' responses that the teachers did not teach quantitative aspects of biology. However, the responses of the teachers indicate that they have been teaching quantitative biology which is contrary to the pupils responses. This indicates that the teachers may not have said the truth. Otherwise, other scholars such as Robeva and Laubenbacher, [12] found that biology educators generally do not emphasize the role of mathematical analysis in the description of biological data and most mathematics courses do not make a connection between mathematical concepts and applications to other fields of science.

4. Conclusion and Recommendations

This study has revealed that the pupils have inadequate skills, irrespective of gender, for tackling questions in mathematical related biology. The contributing factors for this situation included the lack of quantitative competencies amongst biology teachers and the unavailability of appropriate textbooks to guide teachers and students. The biology syllabi and assessment requirements do not compel teachers to teach mathematical biology. Consequently, students exhibited anxiety and a negative attitude towards quantitative biology. The level of mathematical related biology questions in the final national biology grade12 examination is lower than the international. Modern biology has evolved to provide solutions to complex biological and socio-economic challenges, which require and demand the mastery of quantitative methods, skills and tools. It is thus imperative that mathematics becomes integrated into biology curriculum and syllabi right from the secondary school level.

In order for quantitative biology to become an instrument for social and economic change in Zambia, the following recommendations are made. The Curriculum Development Centre, under the Zambian Ministry of Education must enshrine mathematical skills and concepts into the biology syllabus and appropriate textbooks should be written. All assessments, including final biology examinations, should have a substantial percentage weighting given to quantitative biology questions. Teachers' training institutions are supposed to develop new curricula on integrating mathematics into biology, while refresher courses should regularly be organized for in-service biology teachers to improve their competences in quantitative biology. Pedagogical strategies are also required to change the negative attitude of biology pupils towards mathematics. Overall, Zambia requires a new educational policy framework that should drive the integration of mathematics and biology throughout the Zambian educational system.

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