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Exploring Student Mental Models and Student Experiences to Improve the Teaching Practice of Cell and Molecular Biology

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ABSTRACT

Teaching and Learning Biology requires a lot of memorizations of concepts, principles, and laws which may be one of the reasons why students find this area of knowledge highly conceptual. This action research is conducted to improve the teaching practice of Cell and Molecular Biology by investigating and exploring the mental models of students in learning this course under the program, Bachelor of Secondary Education (BSED) Major in Science. This study utilized an action research design by developing learning modules that contain asynchronous tasks which allowed students to design their own concept maps and other visual organizers to explain highly technical concepts in Cell and Molecular Biology. This targets to improve students' critical thinking and enhance comprehension of difficult concepts which were assessed through summative assessments. Based on the results of this study, the students frequently used concept maps and bubble topical organizers or clusters of objects that show linkages among the topics that were discussed in the modules. Students relatively agreed that use of concept mapping helped them organize their ideas in the entire course of cell and molecular biology. This study recommends the testing of this intervention to other disciplines in science education such as in genetics & biotechnology and in anatomy and physiology to establish the consistency of results.

INTRODUCTION

Biology is considered as one of the highly conceptual fields of specialization in science. There are various concepts, laws, and principles amongst its branches that the students must understand, relate, and remember to make their learning cumulative and meaningful (Casadevall & Fang, 2014). Biologists use models in nearly every facet of scientific inquiry, research, and communication. Models are helpful tools for representing ideas and explanations and are used widely by scientists to help describe, understand, and predict processes occurring in the natural world. Concept retention plays a vital role on pre-service teachers as it embodies the content knowledge that they will teach or deliver to their future students in their classroom teaching. High concept retention may also help the pre-service teachers to pass their examinations, especially those tests that are highly conceptual and theoretical in nature (Immordino-Yang *et al.*, 2019).

In the context of conceptual understanding in biology concepts, the students with high conceptual understanding in biology have higher chances to pass biology courses.

As students encounter these numerous biological concepts and consider the challenges in concept retention, Student's knowledge must be consciously arranged into more organized graphic organizers such as concept maps and Venn diagrams so it can also be organized in the minds of the students, through visual maps, for them to easily recall the pieces of knowledge when they need it (Roman *et al.*, 2018).

Utilizing visual concept maps in teaching biology allows the students to improve their critical thinking skills (Raiyn, 2016). Similar recommendations from different fields of sciences appreciate the importance of concept mapping. According to (Joshi *et al.*, 2022), applying concept maps can also improve students' metacognition and problem-solving skills in biomedical sciences whether the learning modality is in online or face-to-face. In the study of (Powell *et al.*, 2021), it suggests that pharmacy students who performed concept mapping had improved their quiz performance.

Furthermore, same observations were gathered from the study of (Choudhari *et al.*, 2021), that the students who shared the assignment of drawing mind and concept maps for topics helped them to easily recall the information learned during the written examination, thus, visual mapping such as Mind and Concept mapping can an effective learning tool in promoting meaningful learning and facilitating rational thinking of the undergraduate students.

This study primarily aimed to improve the teaching practice of Cell and Molecular Biology by integrating the graphic organizers to improve student's mental models on certain topics in this course. The study theorizes that the improvement of student mental models can enhance conceptual understanding and enrich student learning experience. Finally, the results of the study will generate facets from the student responses in their learning experience logs to describe quantitatively their learning experiences for the next cycles of the study.

METHODOLOGY

Research Design

This study utilized educational action research design that

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follows the Plan-Do-Study-Act (PDSA) model to improve the teaching practice of Cell and Molecular Biology in the BSED Science Program students. According to (Brydon-Miller *et. al.,* 2017), action research is the best design to utilize in this study as it shows the iterative nature of its study to document the improvements on teaching practices considering the conceptual understanding and student learning experience, as indicators or variables in the succeeding cycles.

Sampling and Participants

The 32 samples of the students were purposively chosen and the participants were selected based on the following criteria: (1) The students from the College of Teacher Education of the Pamantasan ng Lungsod ng Muntinlupa must be enrolled in cell and molecular biology class under the Bachelor of Secondary Education (BSED) major in Science; (2) students who completed at least 70% of the required course outputs; and, (3) students who are voluntarily agreed to be the participants of the study and to answer the student's learning logs.

Research Instruments

There are 3 research instruments utilized in the study for specific purposes to answer the inquiry questions in this study. This includes:

1. Cell and Molecular Biology Learning Modules (CMBLMs) - these instructional materials are composed of 8 Modules for this course. Out of these 8 modules, only 6 of them have tasks for the creation of graphic organizers. Table 1 summarizes the topic distribution of the modules.
2. Student's Learning Log (SLL)- this instrument is an open-ended google-form questionnaire that is given to the students in their CMBLMs to describe their learning experiences, realization, and reflections after the utilization of these learning modules.
3. Midterm and Final Term Examination. These summative test instruments were given to the students in week 9 (Midterm week) and week 18 (Final term week) of the semester to assess student's concept retention in this course. The Midterm examination is a 50-item test, while the Final term examination is an 80-item test covering the entire topics of the semester.

Research Procedure

The study was done in the 1st semester of the academic year 2021 - 2022. The entire implementation of the study is summarized in Table 2.

Table 1: Content of the Modules in Cell and Molecular Biology

Weeks	**Modules in Cell and Molecular Biology**
Weeks 1 to 2	Introduction to Cell and Molecular Biology (Branches, Biomolecules)
Week 3	Microscopy and Prokaryotes vs. Eukaryotes
Weeks 4 to 5	Cell Structures and Functions
Weeks 6 to 7	Cell Membrane and Cytoplasm
Week 8	Nucleus and Chromosome packaging
Weeks 10 to 12	DNA Replication, Protein Synthesis, DNA Regulation, and DNA Repair Mechanism
Weeks 13 to 14	Endomembrane System
Weeks 15 to 17	Photosynthesis and Cellular Respiration

Table 2 shows the implementation procedures that were followed in the 72-hour conduct of the study. On week 1, the students were oriented about the nature of the course such as the course requirements, grading systems,

Table 2: Implementation Procedures in the conduct of the study

Weeks	**Activities**	**Hours**
1	Course Orientation Collecting Student's Consents General Pretest	**3 hours**
2 - 8	Lecture (1.25 hours) Laboratory (0.75 hour) Exercises and Reflection (Asynchronous - 1.00 hour) Concept Mapping (Asynchronous - 1.00 hour)	4 hours x 7 sessions **28 hours**
9	Midterm Examination covering the topics from week 3 to 8. 1-hour consultation	**3 hours**
10 - 17	Lecture (1.25 hours) Laboratory (0.75 hour) Exercises and Reflection (Asynchronous - 1.00 hour) Concept Mapping (Asynchronous - 1.00 hour)	4 hours x 8 sessions **32 hours**
18	Final Examination (Comprehensive Examination) 1-hour consultation	**4 hours**
Total		**72 hours**

Note: Cell and Molecular Biology is offered in 72 hours as a 4-unit course.

and other course policies. After the course orientation, the student consents were also asked if they were willing to participate as the participants of the study and their responses will be collected as part of the data collection in the study.

In the first session, the course instructor provided a short lecture on graphic organizers which was the main basis of the participants which among these visual materials can serve as their outputs when they are asked to formulate graphic organizers for the lessons in this course. In the implementation proper within weeks 2 to 8 and weeks 10 to 17, each class session was given 4 hours that were subdivided into 1.25 hours for lecture, 0.75 hour for the laboratory, 1 hour for exercises & reflection, and 1 hour for concept mapping that were delivered in asynchronous modalities.The lecture hours allow the course instructor to discuss the essential content of the module. The laboratory activities were conducted asynchronously while the reporting of the results was done in asynchronous sessions. The exercises include post-instruction activities that are designed to reinforce the learnings and promote mastery of the content for each module. Some exercises served as a bridge between the modules to augment one lesson to another. For the written examinations, it will be given in the weeks 9 and 18, coupled with 1-hour consultation with students to inform them about their academic status in this course.

RESULTS AND DISCUSSION

Objective 1

Students utilized different graphic organizers to visually represent their concepts in Cell and Molecular Biology. The competencies that require the students to create graphic organizers were summarized in Table 3. In module 1, table 3 shows the graphic organizers that students utilized in representing their visual concepts about the competencies under the introduction to cell and molecular biology. In competency 1, the two graphic organizers used by the students are bubble topical organizer and Venn diagram. 27 out of 32 students or 84% of the participants have used bubble topical organizers while 5 out of 32 students or 16% of the participants have used Venn diagrams to compare the concepts of cell biology, molecular biology, and biochemistry. In competency 2, the graphic organizer that was utilized by all students was hierarchical topical organizers to characterize the living things from cellular to molecular levels. In competency 3, all students utilized bubble topical diagrams to differentiate the characteristics of biological molecules. The results exemplified similarity with the findings of (Quillin & Thomas, 2015) that the use of drawings is significant for learners to enable their visual model-based reasoning which can be maximized in synthesizing and organizing the ideas in cell biology. Also, as stated by (Yarden *et al.*, 2004), one of the advantages of using graphic organizers as a teacher's technique, it can easily summarize the content of the lectures in introductory lessons in cell biology. In module 2, table 3 shows the graphic organizers that the students utilized in presenting their ideas on microscopy and in differentiating the characteristics of eukaryotic and prokaryotic cells. In competency 1 - about the steps in manipulating microscopy, 29 students or 88% of the

Table 3: Summary of Results for Midterm Topics

Competencies	Graphic Organizers	Frequency	Percentage	Rank
Module 1: Introduction to Cell and Molecular Biology				
1. Comparing Cell Biology, Molecular Biology, and Biochemistryw	Bubble Topical Organizer	27	84%	1
	Venn Diagram	5	16%	2
2. Characterizing the living things relative to cell and molecular perspectives	Hierarchical Topical Organizer	32	100%	1
3. Differentiating the characteristics of Biomolecules	Bubble Topical Organizers	32	100%	1
Module 2: Microscopy and Prokaryotes vs. Eukaryotes				
1. Manipulating Microscopes.	Flow Map	29	88%	1
2. Understanding microscopy.	Bubble Topical Organizer	3	12%	2
3. Differentiating prokaryotic and eukaryotic cells using a graphic organizer.	Venn Diagram	32	100%	1
Module 3: Cell Structures and Functions				
1. Creating a graphic organizer that relates the cellular structures to its functions and processes/activities.	Concept Maps	32	100%	1
Module 6: DNA Replication, Protein Synthesis, Gene Regulation, and DNA Repair Mechanisms				
1. Creating a graphic organizer summarizing the steps of DNA replication, Protein Synthesis, Gene Regulation, and DNA Repair Mechanism	Concept Maps	22	69%	1
	Cluster webs	10	31%	2

participants utilized flow map and 3 students or 12% of the participants utilized bubble topical organizers. According to (Rodrigues-Fernandes *et al.*, 2020), use of digital microscopy application can be easily used to design the flowchart to illustrate the systematics steps in manipulating microscopes.

In competency 2, all students utilized a venn diagram to differentiate the characteristics of eukaryotic and prokaryotic cells. Based on available pieces of literature, use of venn diagrams in comparing prokaryotic and eukaryotic cells is the most frequent to synthesize these concepts among nursing students (Vacek & Liesveld, 2020). In module 3, table 3 shows how concept maps were dominantly utilized in relating the cellular structures to its functions and involved cellular processes. The concept maps summarized the student's knowledge on the chemical composition of the cell and its structure and how these two concepts relate to their cellular activities. In the meta-analysis of (Schroeder *et al.*, 2018) about the STEM and non-STEM, constructing concept maps simplifies the cell concepts and shows relationships of ideas once they are connected. In module 6, table 3 shows the two graphic organizers that were utilized by the students in synthesizing the concepts in DNA replication, protein synthesis, gene regulation, and DNA repair mechanism. 22 of 32 students or 69% utilized concept maps while 10 of 32 students (31%).

In the study of (Demirci & Oktay, 2021), use of concept maps in the teaching of protein synthesis among pre-service biology teachers increased the student's achievement and lessened the misconceptions on the cellular topics. Same findings were observed in the study of (Collins & Nyenhuis, 2021), in which students improved their science learning and concept retention when concept maps were integrated in the teaching of cell biology.

In module 7, table 4 shows that flowchart was the dominant graphic organizer utilized by the students in summarizing the concepts of the endomembrane system in terms of its structures and cellular activities. Students generally represent the individual concepts under specific organelle. Students procedurally illustrated the processes involved per organelle and provided keywords to simplify the content in their flowcharts. In the study of (Sikumbang *et al.*, 2019), pre-service biology teachers' cognitive structure in biology were investigated and according to the findings of this study, it was concluded that use of flowchart in presenting cellular processes significantly helped the students in understanding biological processes of the cell including cell packaging, protein synthesis, and cell transport. In Module 8, table 4 shows how the students utilized Venn diagrams and with some variations added like flowcharts. The students compared the processes of photosynthesis and cellular respiration and including its step-by-step processes. Students were able to identify the components in the chemical reactions including the enzymes involved in photosynthesis and cellular respiration and organized them in the form of Venn diagrams. In the study of (Bergan-Roller *et al.*, 2020), the use of concept maps in teaching cellular respiration helped the students to simplify their understanding in the form of this illustration and established a meaningful learning by connecting the previous knowledge and summarizing them in the form of concept maps.

Table 4: Summary of Results for Pre-final Topics

Competencies	Graphic Organizers	Frequency	Percentage	Rank
Module 7: Endomembrane System				
1. Creating a graphic organizer to summarize the processes/activities of the endomembrane system.	Flowchart	32	100%	1
Module 8: Photosynthesis and Cellular Respiration				
1. Creating a graphic organizer to summarize and compare the processes of photosynthesis and cellular respiration.	Venn Diagram	8	25%	2
	Venn Diagram with Flowchart	24	75%	1

Objective 2

The effect of graphic organizers on conceptual understanding in terms of the pretest and posttest results of the students. Table 5 shows the mean scores in the pretest and posttest of the students in the comprehensive examination before and after the intervention. In the pretest, the mean score is 18.40 ± 9.825 while in the posttest, the mean score is 38.29 ± 5.965. Using the Welch F-test, it was found that there is a significant difference between the pretest and posttest as the p-value is less than 0.05 (p=0.013). It means that the student score significantly increased the student performance when graphic organizers were incorporated in the teaching and learning of cell biology. This result contributes to the teaching practice of cell biology in undergraduate

Table 5: Test of Difference on the Posttest and Pretest (Comprehensive Examination) using Welch F-test

Mean Score		Welch F-test	p-value	Decision on Null	Remarks
Pretest	Posttest				
18.40 (9.825)	38.29 (5.965)	9.480	0.013	Reject	There is significant difference

Note: Standard deviations are in the parentheses

programs as various studies can attest that the use of graphic organizers such as concept maps, flowcharts, Venn diagram, Bubble topical organizers and cluster webs can improve student academic achievement, conceptual understanding, retention, meaningful learning, and motivation (Demirci & Oktay, 2021).

It also improves student visual model-based reasoning and empower procedural knowledge and it lessens students' misconceptions in cell biology (Quillin & Thomas, 2017; Rodrigues-Fernandes *et al*., 2020). The experimental research study of (Choudhary & Bano, 2022) also supports the result of this study in a way that the use of concept maps as an effective way of formative assessment helped the students to summarize their learning concepts in biology, develop their understanding of concepts that eventually lead to promotion of critical thinking and reasoning ability.

Objective 3

As students learn the concepts of cell and molecular biology, their responses in the learning logs were collected and organized through the following themes:

1. *Graphic organizers allow the students to present, organize, and summarize their knowledge in Cell and Molecular Biology in a creative and systematic manner.* During the coding process, the most repeated response, which represents the students' ideas, is the presentations of important concepts to be summarized using graphic organizers. Students are highly concerned in deciding what type of graphic organizers would they utilize to synthesize and logically organize the content of the modules and lectures. According to (Kinchin *et al*., 2019), use of concept maps shows a positive impact on the quality of student learning in various disciplinary contexts and levels of education as it helps the students connect their ideas and generate productive knowledge that are essential in establishing systematic and organized conceptual understanding.

2. *Graphic organizers helped me recall the essential information I need for review and prepare the students for assessment.* For the sample students, graphic organizers purposely serve as their major reviewer in this course especially during the chapter and term examinations. The simplified yet organized knowledge represented in graphic organizers allowed the students to recall the essential concepts during their assessment period and contribute significantly to successful examination results. This idea was parallel to the study of (Srivastava *et al*., 2021) wherein the quality of students map building strategies provide students an opportunity to exercise their working memory and use their assessment strategies and testing skills with sufficient understanding from their graphic organizers.

CONCLUSIONS AND RECOMMENDATIONS

The quantitative and qualitative results based on objectives, the following conclusions were made: (1) the students frequently used concept maps and bubble topical organizers or clusters of objects that show linkages among the topics that were discussed in the modules; (2) the use of graphic organizer improved the student's scores in the pretest and posttest as shown in the comprehensive examination, and (3) students relatively agreed that use of concept mapping helped them organize their ideas in the entire course of cell and molecular biology. Based on the results of the study, it recommends the testing of this intervention to other disciplines in science education such as in genetics & biotechnology and in anatomy and physiology to establish the consistency of results.

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