Enhancing Higher Order Thinking Skills in a Marine Biology Class through Problem-Based Learning

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***Abstract** - The purpose of this research was to examine students' perspectives of their learning in marine biology in the collaborative group context of Problem-based Learning (PBL). Students' higher order thinking skills (HOTS) using PBL involves the development of their logical thinking and reasoning abilities which stimulates their curiosity and associative thinking. This study aimed to investigate how critical thinking skills, particularly analysis, synthesis and evaluation were enhanced in a marine biology class through PBL. Qualitative research approach was used to examine student responses in a questionnaire involving 10 open-ended questions that target students' HOTS on a problem presented in a marine biology class for BS Biology students. Using axial coding as a qualitative data analysis technique by which grounded theory can be performed, the study was able to determine how students manifest their higher reasoning abilities when confronted with a marine biology situation. Results show student responses yielding affirmative remarks on the 10 questions intended to know their level of **analysis** (e.g., analyzing, classifying, inferring, discriminating and relating or connecting), **synthesis** (e.g., synthesizing and collaborating), and **evaluation** (e.g., comparing, criticizing, and convincing) of information from the presented marine biology problem. Consequently, students were able to effectively design experiments to address the presented issue through problem-based learning. Results of the study show that PBL is an efficient instructional strategy embedded within a conventional curriculum used to develop or enhance critical thinking in marine biology.*

***Keywords** – Higher Order Thinking Skills, Problem-Based Learning, Marine Biology*

I. INTRODUCTION

One of De La Salle Lipa's expected Lasallian graduate attributes, along with excellent communication, life-long learning and social responsibility is the development of critical thinking among its students. Critical thinking is thinking clearly and rationally including the ability to engage in reflective and independent thinking. It is important because it serves as real evidence of student learning in the various subjects and discipline in an educational institution. Marin and Halpern (2011) reported that it is also building the foundation of a student's early adult life as he prepares to enter the world of professional adults. Developing critical thinking is essentially incorporated into the various teaching-learning tasks in every curriculum the students engage in. The development of student's critical thinking and higher order thinking skills (HOTS) is considered by many science educators as an important educational goal for students (Dori et al 2003, D' Avanzo 2003, Hmelo-Silver 2004). Bloom's taxonomy of the top domains of learning: analysis, synthesis or creation, and evaluation constitute the higher order thinking skills. Learning and practicing HOTS inside and outside of school will give students the tools that they need to understand, infer, connect, categorize, synthesize, evaluate, and apply the information they know to find solutions to new and existing problems (Quitadamo and Kurtz 2007).

Engaging higher order thinking among students is in turn can be enhanced or cultivated through problem-based learning. Hmelo and Ferrari (1997) discussed the importance of tutorial process in problem-based learning (PBL) and how it can be used to cultivate higher order thinking skills. They further considered the role of the problem, collaboration among peers, the facilitator role, and the importance of student reflection.

Zohar and Dory (2003) strongly suggested that teachers should encourage students of all academic levels (low and high achievers) to engage in tasks that involve higher order thinking skills. Another longitudinal case-study aimed at examining whether purposely teaching for the promotion of higher order thinking skills enhances students' critical thinking, within the framework of science education (Miri et al 2007). Tiwari et al (2006) found significant differences in the development of students' critical thinking dispositions between students who undertook the PBL approach and lecture courses.

Marine biology is a college undergraduate course offered to Biology majors of the institution. It is a 4-unit lecture and lab course that deals with the characteristics of the marine environment and in-depth study of the organisms living in aquatic habitat, covering discussions on the major marine animal phyla – their behavior, physiology, reproductive strategies and ecology, and marine communities: intertidal and sub-tidal, hard and soft substrate, estuaries, plankton, coral reef and deep sea. One topic presented and discussed to these Biology major students is the application of the scientific method on marine biological issues and problems. Through problem-based learning as an instructional strategy, the present work studied responses of students who are expected to come up with an experimental research design addressing a specific marine biological issue presented in the class.

II. METHODS

Qualitative data collection method was adopted in the present study. An open-ended questionnaire consisting of ten questions were answered by sixteen BS Biology students enrolled in Marine Biology course during the 1st Semester SY 2014-2015. Prior to the study, the students were given a review lesson on the scientific method and its applications in marine biology problem solving. The participants were then grouped into four groups with four members each. They were presented with a marine biological problem and through collaborative group work they were tasked to discuss and come up with experimental designs that would suit to solve the given problem. The problem states: *"Imagine you are a marine biologist and you notice that a certain type of crab tends to be larger in a local bay than in the waters outside the bay. What hypotheses might account for this difference? How would you go about testing these hypotheses?"*(Hubert & Castro, 2013)

The Problem-based Learning (PBL) Seven Step developed in the University of Maastricht, The Netherlands (in De Graaf & Kolmos, 2003) was the main learning framework used. This framework includes two learning sessions (1 and 2) with an intersession (Step 6. Self-study). Session 1 includes five steps: 1. Clarifying concepts, 2. Defining the problem, 3. Analyzing the problem – brainstorming, 4. Organize facts and knowledge, and 5. Formulate learning objectives. Session 2, on the other hand includes Step 7. Discussion. The instrument was then administered to the participants after the problem-based learning and group presentation sessions.

Responses were subjected to content analysis with axial coding approach to explore the narrative themes on students' experiences and perspective of their critical thinking on the problem presented. This was also done to summarize the students' main ideas and to make valid inferences from the connections among critical thinking and problem-solving skills using higher order thinking. Axial coding was used in the descriptive analysis where an axis or central character or phenomenon was identified. Different dimensions around this axis were then extracted from the student responses: condition, context, interactional strategies and consequences. No statistical treatment of data was performed since the present study utilized the qualitative research approach.

III. RESULTS AND DISCUSSION

On the analysis domain *(e.g., analyzing, classifying, inferring, discriminating and relating or connecting)*. Analytical reasoning skills enable people to identify assumptions, reasons and claims, and to examine how they interact in the formation of arguments. Based on findings, students analyzed the marine biological issue presented in the class. Specifically, they were able to classify the dependent and independent variables, formulated a problem-related inference, discriminated between experimental designs and related or connected the marine biological issue to real-life situations. Students' higher order thinking skills, in particular with the analysis domain, were clearly seen based from the experiences obtained. To illustrate, students are in unison that analysis "*leads to good understanding of the situation*", "*formulation of a problem*", and "*enables performing the steps in the scientific method efficiently*", which ultimately "*leads to the possible answer or solutions to the case or issue*". Results reveal students' critical analysis experiences

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ranged from "*sharing, plotting and imagining ideas related to the problem*" to "*examination of details relating it to prior knowledge gained through the years as Biology students*". Some students also did "*necessary observation, identification of causes, application of knowledge from past journal article readings and designing of experiments to address the problem*". Results will suggest that students with strong analytical skills attend to patterns and to details, able to identify the elements of a situation and determine how those parts interact.

On the other hand, students were able to classify the independent and dependent variables primarily "*to have focus on the main problem and not be confused on the various factors presented*" and "*to further understand the nature of a biological problem or issue"*. Students did this on purpose to "*help [us] choose which conditions manipulate the change/s occurring in the experimental subject*", "*help in generating a hypothesis*" and "*to be able to know their relationship, by what is to be expected given that they are interacting with one another*". A student is aware that classifying both variables helps "*to determine which* [of the variable] *is being changed or manipulated in the experiment and the affected variables*" As a result, students hypothesized that "*crabs in the local bay are larger in size than those found in the open oceans*" due to certain local environmental impacts, leading them to design varied experiments to test their hypotheses. Students' critical analysis on variable classification and inference formulation lead to expected outcomes, i.e., they reported that "*the dependent variable is the crab size, since it is being affected by the independent variable which is the environmental conditions*". These conditions can include food items, physical-chemical properties of water, nutrient levels, population size, predation and competition, and gender-size correlation variation, as can be seen in the results.

Critical analysis of a biological problem is a pre-requisite before self-learning can occur. D'Avanzo (2003) suggested that this mental exercise is an example of metacognition, which is a problem-solving skill or strategy students use to monitor their learning and control their attention. In the study, students used their metacognitive skills to summarize main points, analyze the meaning and implications of a text, and recognize when they fail to comprehend an idea. Students are one in saying that formulation of scientific inference is important "*to know both dependent and independent variables, and to fully analyze the marine biological issue*" and "*to think of more valid experiments based on facts that [*we*] already know and what the results will become*". According to a student, "*educated guesses are done in order to prove something or to make more scientific researches that may contribute to the development of the scientific society*". Metacognition has been described as knowing what is known and not known, using self-teaching skills, and employing student-centered as opposed to teacher-centered learning (Bransford et al. 1999 in D'Avanzo, 2003).

On the synthesis domain *(e.g., synthesize and collaborate).*Student skills in synthesizing information enable one to draw conclusions from reasons and evidence. Inference skills indicate the necessary or the very probable consequences of a given set of facts and conditions. The study shows that students synthesized the details of the given marine biological issue/problem. According to one student, *"synthesizing details was done by identifying the problem, observation, and experimentation, leading to different approaches that can be done to yield results"*. Synthesizing details in a more substantive way is aimed to "*know the different factors that influence a specific marine biological issue", "to have organized and detailed points regarding the issue",* and "*to educate students on how to improve their abilities to make more acquired procedures for the experiment*".

The students were able to do this collaboratively within the group "*by sharing ideas and prior knowledge to each other"* and *"by making it detail by detail to come up with a convincing experiment and a good conclusion*". Moreover, students specifically *"did sharing to the group prior knowledge about crabs, site or location, and the issue itself, leading to its possible solutions"* and *"by thinking of the possible changes that could happen to each variable when one is manipulated"*. As a result, students were able "*to hypothesize on the different factors that affect crab's life, growth and survival"; "able to devise and experimental set-up to address the problem and were able to identify both dependent and independent variables";* and *"looked on the different angles and considering all factors that would affect the crab sizes in the two different sites of the study"*.

Developing ability of students to synthesize information enables them to create new ideas, predict and draw valid conclusions from their different sorts of observation. Results of the study revealed that students were able to create relevant information to assist them in solving the given problem/issue. Moreover, collaboratively working on the problem will yield more positive learning outcomes: active participation in the learning process including self-direction, identification of own learning needs, teamwork, creative discussion and learning from peers; and the integration and synthesis of a variety of knowledge (Cooke and Moyle 2002). The main concern of PBL is self-directed learning which links knowledge to practical applications through the use of collaborative groups in which students are responsible for deciding what is to be learned (Hmelo-Silver 2004). Collaborative learning is premised on Vygotskian concepts that define learning as the social construction of knowledge.

Collaborative work with other members of the group was also deemed essential by all students. Results of the study show that evidently, students are aware that in a collaborative work, "*all members were given a chance to share their insights and from these ideas the group decided to focus on one, single common point*". While doing the activity, students realized that collaboration will be *"more effective if we will have more available options*", thus it is "*a matter of sharing knowledge, thoughts and perceptions to the group*". One student said that "*a good researcher should have an open mind. He should know how to accept suggestions from others since Biology is not an exact science, it is changing. It is done through brainstorming and evaluating each suggested idea*".

Collaboration is important because one student said "*it is needed to discuss how the experiment can be designed*". Moreover, students shared that group work is significant "*to yield more answers and still more questions that can be asked*", to "*generate or make more reliable group output*", and to have "*strong arguments being made ready to collaboratively work with others, trying to avoid straying away from the given problem or issue*", thus "*trying to focus more on the identified problem*". Collaborative or team-based work enabled students to think creatively in terms of enhancing their important skill in the scientific method. McInerney and Fink (2003) reported that team-based learning with challenging projects improved the students' comprehension and retention of information, critical thinking, and attitudes in a microbial physiology course and focused student-instructor interactions on learning. In the present study, students recalled experiments from their respective undergraduate theses since most of them are already working with their topics regarding aquatic species. Thus, as a result, students were able to work more fruitfully "*because it is much easier to work together*". A fundamental rationale for instructional strategies that promote the cooperation between learners is that such strategies more closely approximate the "real world" than traditional didactic approaches. That is, activities requiring cooperation among individuals reflect how tasks are usually accomplished in practice.

On the evaluation domain *(e.g., comparing, criticizing and convincing).* Evaluative reasoning skills enable students to assess the credibility of sources of information and the claims they make. Strong explanation skills can support high quality evaluation by providing the evidence, reasons, methods, criteria, or assumptions behind the claims made and the conclusions reached. The present study found that students were able to effectively evaluate (i.e., compare and criticize) their group output with those of other groups. When students compare, they are evaluating the pros and cons of their experimental design outputs, thus they are able to assess the value and make recommendations (Bloom 1956) about their experiments. To illustrate, one student said they compared because there is "*a need to find for more effective solutions/experimental designs that will address the problem*". Students are also one in saying that comparison is essential so that they will become "*more exposed to different ideas and approaches of others*" and also be "*collaborative and active seeker for other solutions that may best fit to answer the problem*". Further, this approach enabled them to "*getting more additional information*" and "*needing to have better research results on the next experiments*" or problems that they will encounter. On the other hand, findings suggest that students were also critical on their experimental design outputs. According to students, critical analysis is important to "*yield better research results*". Likewise, constructive criticisms will augment the critical thinking of one person and "*it should be done in an atmosphere of openness and honesty*". A student further said that being critical is important "t*o be able to improve what needs to be improved and to point out some essential points regarding the problem/issue*". Further, students said that "*critical analysis is needed in order to decide which among the choices is the best and most appropriate experimental research design*" for the identified problem/issue. Finally, students were also "*enabled to determine and make an observation about the marine biological problem*", where good inferences and hypotheses can be formulated. Students often use these evaluative skills to determine the strength or weakness of arguments. They can judge the quality of analyses, interpretations, explanations, inferences, options, opinions, beliefs, ideas, proposals, and decisions applying these evaluation skills.

Results reveal that there is also a degree of variation among the students' strategies in doing comparison and critical analysis. Some students compare by "*listening to and seeing some details that were forgotten from collaborative work*" and by "*sharing their output and explaining why they came up with their presented ideas*". Other students compare by "*presenting outputs one by one and having other groups criticize each others' work*" or "*discussing outputs in the class where students asked questions for clarifications while others having their suggestions*". Nonetheless, all these comparisons were conducted through class discussion and/or presentation which most students prefer as an effective instructional strategy. On the other hand, several experiences were also noted by the students in critically analyzing their experimental designs. To illustrate, students were able to identify "*experimental and descriptive approaches as ways or approaches in solving a particular marine biological issue*". In addition, "*they listened and critically analyzed other group's outputs, doing some brainstorming on the problem/issue at hand*". Students are one in saying that "*by carefully thinking and evaluating things on how the experiment will work better*", "*several points will be raised and were hoped to be changed or improved*". Thinking critically definitely lead them "*to use the most plausible and reliable experimental design to address the problem/issue*".

As a consequence of the PBL employed, students learned that there are "*lots of possible solutions to the identified issue/problem*" because "*some other groups' works were different in terms of the concepts and techniques used*", consistent with results of Yuan et al (2008). The students' experiences on the enhancement of their critical are consistent with our aim as college instructors, i.e., to teach students to learn how to evaluate new information from an educated and skeptical perspective (Adams 2003). Critical thinking is compatible with students thinking "out-of-the-box", challenging consensus and pursuing less popular approaches. To illustrate, the following will show the varied experimental designs the students were able to propose in class:

1) counting macro-invertebrate food items that the crabs consume to know crab feeding biology and growth,
2) testing effects of various factors such as water quality, food availability and specific resources needed by the crabs,
3) measuring crab length-weight parameters separated into two cages, actual estimation of crab age (i.e., more indicative of differing crab sizes),
4) making a cage in both sampling sites that will then be placed with crabs from the local bay and from the open ocean,
5) examining effects of population size difference,
6) gender-size correlation variation,
7) effect of presence of predator and competition, and
8) theoretical consideration of all possible aspects that could influence the crabs' growth and survival in both the local bay and open ocean.

Results of the study will show that some experimental designs were too simple and some were outliers to the overall experimental designs that were considered. Nonetheless, making an experimental design requires closely related features where methods are not too far away from each other. Findings suggest that by using PBL, students seek and evaluated the information they acquire related to the problem they are given to solve. Students' critical thinking was enhanced in the problem-based learning activity because they were able to define and analyze the problem, identify and find needed information (by posing and answering their own and peers' questions), share the results of their investigations, and ultimately to design alternative experiments (Allen & Tanner, 2003) required to solve the marine biological problem. Hmelo and Ferrari (1997) reported that activities that involve inquiry learning include problem framing, data gathering, divergent thinking or idea generation, evaluating alternatives, and applying a solution to the problem.

IV. Summary and Conclusion

This qualitative study was able to show students' perspectives and experiences in enhancing their critical (higher order) thinking skills in a marine biology undergraduate class. Using problem-based learning and working in collaborative groups, students manifested their critical thinking on the top three domains of learning in the Bloom's Taxonomy (i.e., analysis, synthesis and evaluation). Based on the findings, students were able to classify the dependent and independent variables, formulated a problem-related inference, discriminated between experimental designs and related or connected the marine biological issue to real-life situations. Results also suggested that students synthesized the details of the given marine biological issue/problem working collaboratively with other members of the group. The present study also found that students were able to effectively compare and criticize their group output with those of other groups. The students were also able to come up with varied experimental designs proposed in class to solve the given marine biological issue or problem. It is the ultimate hope of the present study to help in the formulation of a guide which is designed to help teachers create student activities and test items that measure a variety of higher level thinking abilities among students. Further, learning the application of the scientific method through problem-based approach as an instructional strategy in a marine biology course fostered higher order thinking skills among students.

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