# UNIVERSITY OF THE PHILIPPINES

**Doctor of Philosophy in Education**
**(Major in Chemistry Education)**

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# Mereology-based Instruction: Effects on Chemical Identity Thinking, Critical Thinking and Chemistry-based Health Literacy

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# APPROVAL SHEET

This dissertation of **Jonathan M. Barcelo** attached hereto, entitled **MEREOLOGY-BASED INSTRUCTION: EFFECTS ON CHEMICAL IDENTITY THINKING, CRITICAL THINKING AND CHEMISTRY-BASED HEALTH LITERACY**, in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Education (major in Chemistry Education), is hereby accepted.

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# ABSTRACT

This study is an attempt to utilize mereology-based instruction, an innovative approach in teaching biochemistry to health science students by linking biochemistry principles to health concepts. Specifically, it investigated the effects of mereology-based instruction (MBI) and conventional instruction (CI) to the chemical identity thinking (CIT), critical thinking in chemistry (CTC), and chemistry-based health literacy (CbHL) of medical laboratory science students. A total of 13 intact classes of second year Medical Laboratory Science were randomly assigned into two groups, mereology-based instruction and conventional instruction. Seven intact classes (N = 290) were assigned to the mereology-based instruction group and six intact classes (N = 287) were assigned to the conventional instruction group. The students participated in the study for 12 weeks in a tertiary private academic institution in Baguio City. Data were obtained using Rasch analysis, an approach of mathematical modelling anchored on a latent trait to measure person ability and item difficulty related to the latent trait in a single logit scale. Mereology-based instruction was found to be more effective than conventional instruction in increasing chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy of health science students, but these students exposed to MBI experienced higher cognitive load. The effects of MBI in chemical identity thinking (CIT), critical thinking in chemistry (CTC) and chemistry-based health literacy (CbHL) is topic-specific, and has an "enhancement" effect in CIT, "corrective" effect in CTC, and either "corrective" or "enhancing" effect in CbHL. Conventional instruction has a "corrective" effect in chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy. Based on multiple linear regression analysis, an increase in posttest ability of students in chemical identity thinking is predicted by prior knowledge of chemistry concepts, pretest ability in chemical identity thinking, and male gender in the MBI group. In the CI group, student posttest ability in chemical identity thinking is predicted by prior knowledge of chemistry concepts and pretest ability in chemical identity thinking. An increase in posttest student ability in critical thinking in chemistry in the MBI group is predicted by prior knowledge of chemistry concepts, prior knowledge of visual representations and pretest ability in critical thinking in chemistry. In the CI group, an increased posttest student ability in critical thinking in chemistry is predicted by prior knowledge of chemistry concepts, prior knowledge of visual representations, pretest ability in critical thinking in chemistry and male gender. An increase in posttest student ability in chemistry-based health literacy is predicted by prior knowledge of visual representations, pretest ability in chemistry-based health literacy, male gender, and cognitive load in the MBI group. In the CI group, student posttest ability in chemistry-based health literacy is predicted by prior knowledge of chemistry concepts and pretest ability in chemistry-based health literacy. Results indicate that mereology-based instruction in biochemistry has a potential to address the expected learning outcomes in health science programs in the Philippines as it promotes a thinking process which targets misconceptions and enhances prior level of conceptual understanding related to chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy. Achieving these learning outcomes is deemed to be effective in building the capacity of future health science graduates in making appropriate and robust health-related decisions.

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# CHAPTER 1

# INTRODUCTION

This chapter introduces the study in light of biochemistry education in health science programs. The study discusses the current scenario of biochemistry instruction in health science programs at the tertiary level, the limitations of the current teaching strategies, and the rationale for introducing a novel biochemistry instruction. This chapter presents the statement of the problems, significance of the study, and scope and delimitation of the study.

## Background of the Study

Biochemistry has long been regarded as relevant to health. It has been praised for its contributions to medical breakthroughs in pharmacology, diagnostics and nutrition. Clearly, biochemistry improves national and global health outcomes. In fact, biochemistry education in the health science programs has emphasized the link between biochemistry concepts and health (Armstrong & Foe, 2020; Azzalis et al, 2012; Chen & Ni, 2013; Goeden et al., 2015; Matlin et al., 2017; Schroeder et al, 2017) through the teaching of biochemistry content related to health, as well as deepening knowledge about health topics through understanding its biochemistry context. Biochemistry education in the Philippines has also adopted the same rationale in preparing the topics necessary for students to learn, in the hope of improving health outcomes in the Philippines.

But the health status of Filipinos still remains poor, despite having a yearly production of thousands of nurses, doctors, medical technologists and midwives (Dayrit et al., 2018). What is more disconcerting is that health literacy among Filipinos is poor at different age ranges (Agosto et al., 2018; Camiling, 2019; Javier et al, 2019). Ironically, biochemistry is among the subjects commonly taken by these health care workers, yet biochemistry is still detached from health outcomes. It has been observed that globally, the extent to which developing countries can achieve international health targets depends on the capacity to generate, harness, and apply science and technology (de Leon et al, 2019). Biochemistry education in health education programs has been designed to improve content knowledge. Thus, there is a need to revisit the teaching of biochemistry in the health sciences to address the Philippine health targets.

While it is acknowledged that health *per se* is a complex socio-scientific issue which requires multiple approaches and perspectives, there are some issues in biochemistry education that this study wishes to clarify – what exactly should be the role of biochemistry education in health science programs? Should biochemistry education focus on learning concepts to improve content knowledge, or should it also consider the reshaping of students' thinking process and emphasize the role of biochemistry in improving health? Why not use biochemistry education as a catalyst for addressing independence in achieving an optimal level of wellness? This study approaches these issues by proposing a teaching intervention in biochemistry for health science programs.

Previous approaches in teaching biochemistry focused on structure-property relationships (Taber, 2013), visual literacy and visual representations (Bussey & Orgill, 2015; Herman et al., 2006; Linenberger & Holme, 2014), and analogy (Avargil et al., 2015; Orgill et al., 2015; Sarantopoulos & Tsaparlis, 2004) and inclusion of threshold concepts (Loertscher et al., 2014). Other studies included animal models (Jiao et al., 2014), and case studies (Brass, 2013; Figueira & Rocha, 2013; McRae, 2012). However, these studies did not emphasize the thinking processes that translate to outcomes in a local or national scale.

Some studies in biochemistry education also focused on improving laboratory skills in basic instrumentation (Ciancaglini et al, 2001; Erasmus et al., 2015; Gliddon & Rosengren, 2012; Jiao et al, 2014; Peacock & Grande, 2015; Powers et al, 2007). But there is a lack of emphasis as to how these skills contribute to outcomes which address socio-scientific contexts. There is also a lack of variation in teaching biochemistry in health-related courses and science courses. Biochemistry instruction for health sciences students seem to be the same as it is taught to chemistry students. If biochemistry education for health sciences students in the Philippines is aimed solely on improving conceptual understanding of biochemistry concepts, the resulting curriculum may be difficult, congested, and irrelevant to the expected outcomes for a health care professional.

Based on the current sociocultural and economic characteristics of Filipinos, this study proposes that health science students must possess three competencies to link biochemistry knowledge to health and its role in achieving health outcomes – the ability to correctly characterize a substance, use critical thinking when studying chemistry concepts and correctly link chemistry concepts to support a health decision. Knowledge about chemical attributes of substances is important because it helps justify why substances cannot be replaced by mixtures and vice versa. A lack of chemical knowledge promotes negative perceptions about chemistry, leading to chemophobia (Saleh et al., 2019). Critical thinking in the context of chemistry is relevant to untangle biochemical information from *in vitro*, *ex vivo* or *in vivo* contexts. Lastly, linking chemistry concepts to health decisions is relevant in terms of correcting pseudoscience and false scientific claims related to nutrition, diagnosis of illnesses, and the appropriate use of medicines.

Biochemistry concepts are introduced too early in the curriculum of health science students. With this set-up, students are forced to contextualize chemical concepts to health immediately, even without completely understanding the characteristics of *in vivo* chemical systems. Attempting to contextualize biochemistry to health at an early stage is difficult and may promote confusion, since students' background about health-related concepts is still incomplete. Thus, students often resort to rote memorization and finding patterns or simplifying biochemistry concepts into rules. Such an approach in learning biochemistry may be detrimental to the development of adequate critical thinking and health literacy in the health sciences. Failure to develop adequate understanding of biochemical concepts also results to blindly following protocols or giving misleading or confusing explanations (Brown et al., 2014).

Using chemistry concepts in supporting health decisions is also neglected in health science programs. Most studies in biochemistry education are focused on medical literacy which emphasizes the study of communicable diseases, lifestyle-related diseases, and metabolic disorders (Azzalis et al., 2012; Harrison et al., 2012), human therapy (Baeuerle & Murry, 2014), and biotechnology (Azzalis et al., 2012). Lastly, not all teaching strategies in biochemistry are gender-biased. Most students who enroll in health-related courses than female students (Brown et al., 2011; Limiñana-Gras et al., 2013; Ousey et al., 2014; Palmgren et al., 2011; Payne et al., 2013; Sunkad et al., 2015). The curriculum, assessment and evaluation need to be designed according to the population profile of an institution.

With these *a priori* conditions reported in literature, it is essential that biochemistry instruction in health science programs in the Philippines should incorporate activities which promote conceptual understanding in both lecture and laboratory components, visual representation skills, minimal analytical skills, and a common thinking process which can be applied in learning biochemistry concepts in the context of health. Thus, the crafting of a mereology-based instruction in teaching biochemistry, or the use of *part-whole* relationship is put forth in this study.

However, it should be emphasized that mereology-based instruction does not involve teaching *part-whole* relations in biochemistry (since it has false presuppositions in chemistry). A part-whole relationship is based on determining the attributability of a "part" to a "whole." But in a chemistry context, claiming that the property of a substance is a sum of the attributes of its molecular components has faced criticisms due to incorrect simplification. Furthermore, the properties of substances result from the interactions of its molecular components (Talanquer, 2017). For example, the boiling point of a pure substance is influenced by intermolecular forces of attraction among molecules comprising it.

It has been claimed that chemistry does not fit into a part-whole relationship or mereology when the context is pertaining to atoms and molecules (Harré & Llored, 2013; van Brakel, 2014). With the limitation of applying a part-whole relationship to a molecular context, chemistry concepts cannot be simplified by mereology. In this study, mereology-based instruction has been designed by the researcher as the utilization of incorrect or over-simplified claims using part-whole relationship as opportunities for eliciting a thinking process that can be applied in health contexts such as nutrition, diagnostics and pharmacology within the current context of health outcomes in the Philippines. In this way, the goal of biochemistry education for health sciences becomes more realistic, more focused and more discipline-specific.

To the author's knowledge, there has been no study about addressing competencies required from health science students through *part-whole* relationship. Furthermore, very few researchers in biochemistry education have deviated from the improvement of conceptual understanding exposition as a primary goal in health science programs. This study asserts that biochemistry concepts are conceptual scaffolds not only to understand complex topics in various disciplines (Ashfar & Han, 2014; Brenner, 2013), but to address socio-scientific issues such as health literacy and improvement of health outcomes. Hence, this study has a new contribution to biochemistry education in the health science programs.

## Statement of the Problem

This study primarily aims to determine the effects of mereology-based instruction in biochemistry, which is based on *part-whole* relationships, to chemical identity thinking, critical thinking and chemistry-based health literacy of second year medical laboratory science students, in contrast to conventional instruction, which is based on *structure-property* or *structure-function* relationships.

Specifically, the study sought to answer the following questions:

1) What is the level of difficulty of items related to prior knowledge of chemistry concepts and prior knowledge of visual representations in the mereology-based instruction (MBI) group and conventional instruction (CI) group?
2) After controlling for prior knowledge of chemistry concepts and prior knowledge of visual representations, is there a significant difference between students exposed to MBI and to CI in terms of posttest chemical identity

thinking (CIT), posttest critical thinking in chemistry (CTC) and posttest chemistry-based health literacy (CbHL)?

3) Taken simultaneously, are the variables gender, prior knowledge of chemistry concepts, prior knowledge of visual representations, pretest ability in chemical identity thinking (CIT), and mean total cognitive load positive predictors of posttest ability in chemical identity thinking (CIT)?
4) Taken simultaneously, are the variables gender, prior knowledge of chemistry concepts, prior knowledge of visual representations, pretest ability in critical thinking in chemistry (CTC), and mean total cognitive load positive predictors of posttest ability in critical thinking in chemistry (CTC)?
5) Taken simultaneously, are the variables gender, prior knowledge of chemistry concepts, prior knowledge of visual representations, pretest ability in chemistry-based health literacy (CbHL), and mean total cognitive load positive predictors of posttest ability in chemistry-based health literacy (CbHL)?

## Significance of the Study

This study is significant to biochemistry instructors in the Philippines, curriculum developers of chemistry subjects for health science students, authors of textbooks for biochemistry related to health, and health science students. The biochemistry concepts studied by health science students are contextualized to health. Hence, this present study can address the thinking processes required among health science students: chemical identity thinking, critical thinking and chemistry-based health literacy.

Several biochemistry instructors who teach health science students are faced with the challenges of teaching biochemistry to students who often perceive biochemistry to be difficult to learn and irrelevant to the health science program. Furthermore, biochemistry teachers may face difficulty in promoting critical thinking among health science students to prevent the practice of concept simplification and automaticity of reasoning. The results of this study can determine the focus of biochemistry content in the health sciences such as structure-function relationship which is contextualized to health promotion, diagnostics, and pharmacology. The utilization of mereology in learning the nature of biochemical entities also differentiates an *in vitro* chemical environment to *in vivo* chemical environment, thereby preventing assumptions related to automaticity of reasoning and concept simplification.

Lastly, students can benefit from the results of the study. The activities selected for mereology-based instruction has the potential to address and correct misconceptions related to heuristic reasoning and inaccurate simplification of biochemistry concepts. The correction of misconceptions in biochemistry is highlighted and can be used to modify lifestyle-related decisions to maintain good health and promote chemistry-based health literacy to individuals, families and communities.

## Scope and Delimitation of the Study

The objective of this study was to determine the effectiveness of mereology-based instruction based on changes in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy. The results apply to the health science programs which require biochemistry as a prerequisite to their professional health-related subjects. Furthermore, the results are also applicable to health science programs which have professional subjects that require integration of biochemistry concepts in health education subjects.

The study is delimited to second year BS Medical Laboratory Science students from an educational institution in Baguio City during the first semester of academic year 2019 – 2020. The study also implemented the intervention while the course offering was not changed. The selection of topics in the intervention was based on the current course syllabus in Biochemistry offered for BS Medical Technology.

Random assignment of intact classes to mereology-based instruction and to conventional instruction was done since random assignment of students is not permitted. Teaching load was assigned by the department head so the classes assigned to the biochemistry instructors were the classes they taught during the implementation of either conventional instruction or mereology-based instruction. All prospective biochemistry instructors were trained in implementing mereology-based instruction and conventional instruction for five days.

Another delimitation of the study was that there was no opportunity for the researcher to observe and monitor the conduct of each type of instruction. The researcher did not teach any class in either conventional instruction group or mereology-based instruction group to remove researcher bias since bias may be inadvertently introduced to the classes handled by the researcher, thus compromising the accuracy of the results obtained in the study. Departmental examinations were not based on either type of instruction, but on the contents of the lecture learning material and laboratory procedures only.

Furthermore, the teaching method was implemented based on the weekly plan of activities which are disseminated by the researcher in a bimonthly or monthly basis. The teacher-implementors consulted the researcher for the preparation of the laboratory reagents, evaluation of arguments using the Toulmin Argumentation Pattern and checking of laboratory notebooks and evaluation of laboratory activity performance and laboratory reports in order to ensure that all laboratory outputs were evaluated objectively based on the specific objective of each QSAR laboratory activity. There was no documentation of feedback from the teachers and no monitoring was done during the actual performance of laboratory activities and argumentation activities due to conflicts in schedule of the researcher and some of the laboratory class schedules. However, the concerns of the teachers were addressed at the soonest possible time by the researcher online via email or as necessary. Meetings were conducted at the faculty room after the last classes. The schedule of the meetings was as follows: July 29, 2019, August 5, 2019, August 19, 2019, September 9, 2019, September 23, 2019, October 21, 2019, and November 4, 2019. When teachers are unable to attend the meetings, the discussions were sent via email to guide the teacher in implementing either conventional instruction of mereology-based instruction.

In order to avoid teacher bias, the teachers were oriented at the start of the month of the school year on the procedures in the laboratory manual and guidelines on how to prepare the laboratory reports, laboratory notebooks and the argumentation output. If a learning cycle is completed, teachers are requested to attend a meeting to discuss the next cycle of learning activity. Hence, some meetings were done twice a month, except during suspension of classes due to school activities or typhoons.

The teachers were also reminded on how to implement conventional instruction and mereology-based instruction to avoid introducing another strategy which might cause teacher bias in terms of the delivery of the lesson and performance of the QSAR laboratory activities. Clarifications on how to instruct using the conventional instruction and mereology-based instruction were addressed during meetings or via email to ensure that the teachers adhere on how to teach using either conventional instruction or mereology-based instruction. During meetings, teachers were also reminded on how to deliver the lessons in the conventional instruction and mereology-based instruction lecture classes.

In addition, teachers were requested to use the contents of the lecture learning material and prescribed journal articles only to avoid introducing variations in the implementation of each type of instruction. Since the CDs containing all learning materials, laboratory manuals and journal articles were provided to students, teachers were instructed to refer to the contents of the CD only when teaching the concepts. Furthermore, teachers were instructed not to deliberately answer the research questions during post-lab discussions and discuss the correct answers to arguments to avoid suggesting correct answers to students. As instructed during the teacher training, the teachers are only allowed to guide students in discussing concepts in the lecture learning material and facilitate the performance of each QSAR activity.

Teachers were also instructed to require students to answer the laboratory questions, research questions and argumentations independently and collaborate with their group members. If the teachers would like to introduce a reference, the researcher arranged a meeting to ensure that the additional reference should be given to both conventional instruction group and mereology-based instruction group. However, one delimitation of this study is the individual efforts done by the students to learn the material on their own as the researcher did not monitor each student when learning the concepts via the provided learning materials.

The quantitative structure-activity relationship laboratory activities were adapted based on existing biochemical research literature. However, method optimization, selection of assay, manner of presentation and use of linear regression using two molecular descriptors were not copied elsewhere and was designed to target the learning outcomes only. Implementation of activities were supervised carefully to avoid misinterpretation of results, and do not represent the actual results in high-end QSAR researches.

Argumentations were patterned using syllogisms and may still be susceptible to logical fallacies *per se*. In addition, inclusion of few chemistry-related details in the argument was a deliberate attempt to elicit deep conceptual chemistry-based reasoning from students in mereology-based instruction and conventional instruction.

In this study, Rasch analysis was used to convert the non-linear raw scores of students in all research instruments into linear units called logits and to ensure that each research instrument has adequate psychometric properties which guarantees correct interpretation of data. Based on item response theory, raw scores are considered non-linear, and subjecting raw scores to statistical tests may result to wrong or distorted interpretations (Boone et al., 2014). Furthermore, all research instruments were ensured to measure the embedded latent variable of construct by using dichotomous Rasch analysis, Rasch partial credit modelling and Rasch rating scale model to ensure that the measured student ability parametric statistical analyses. A stacked analysis was performed to ensure the accurate measurement of changes in student ability during pretest and posttest while racked analysis was conducted to ensure an accurate measurement of item difficulty changes during pretest and posttest.

## Duration

Mereology-based instruction and conventional instruction were implemented for 12 weeks within August to November 2019. Each week is equivalent to three days of one-hour lecture sessions and two-hour laboratory sessions. The number of weeks for implementation excluded departmental examination weeks, suspension of classes, preliminary exposure of all students to *in silico* analysis using ChemDes and MolView, student orientation, and performance of *in vitro* biochemistry assays to familiarize students with quantitative image analysis using ImageJ.

## Characteristics of Biochemistry Teachers

Mereology-based instruction and conventional instruction groups were facilitated by seven biochemistry teachers. In most cases, the teacher in the lecture class is also the one handling the same class in the laboratory. However, since some are contractual faculty members, some teachers teach the lecture class while another teacher teaches the laboratory class. All biochemistry teachers are graduates of the BS Medical Laboratory Science or BS Medical Technology program. Three biochemistry teachers have MS degrees in the field of medical technology. The teaching load and schedule of the biochemistry teachers were not controlled and were merely based on the designation of the department head prior to the start of the semester. The teacher characteristics are presented in Table 3.1.

**Table 1.1.** Profile of biochemistry teachers

| Teacher code/ gender/ age | Number of years teaching biochemistry | Academic Qualifications | Classes handled | |
|---|---|---|---|---|
| | | | Lecture | Lab |
| MAB, M, 33 | 2 | BSMT, MSMT | 4 classes<br>(2 MBI, 2CI) | 4 classes<br>(2 MBI, 2CI) |
| PLGA, F, 26 | 2 | BSMT, MPH (ongoing) | 2 classes<br>(1 MBI, 1CI) | 2 classes<br>(1MBI, 1CI) |
| JRDG, F, 26 | 2 | BSMT, MPH (ongoing) | 2 classes<br>(1 MBI, 1CI) | 2 classes<br>(1 MBI, 1CI) |
| DAB, M, 28 | 2 | BSMT, MSMT (ongoing) | 4 classes<br>(2MBI, 2CI) | 2 classes<br>(1 MBI, 1CI) |
| HA, F, 24 | 2 | BSMT, MSMT (ongoing) | - | 2 classes<br>(1MBI, 1CI) |
| KE, F, 35 | 2 | BSMT, MSMT | 1<br>(1MBI) | - |
| EF, M, 30 | 2 | BSMT, MSMT | | 1<br>(MBI) |

# CHAPTER 2

# REVIEW OF RELATED LITERATURE AND CONCEPTUAL FRAMEWORK

This chapter on the review of related literature explores and contextualizes the proposed intervention- mereology-based instruction- to biochemistry education in the health sciences. Related studies in chemical identity thinking, critical thinking, and chemistry-based health literacy are also discussed as to why they are needed in health science programs. Other studies which may influence the effect of the proposed intervention to the intended competencies are also described. Lastly, the conceptual framework, research hypotheses and the operational definitions which are used in this study are discussed.

## Biochemistry Education in Health Sciences

The goal of biochemistry education in the health sciences is to teach both biochemistry concepts and health concepts. However, studies have varying foci whenever health contexts are integrated to biochemistry instruction. Some studies focused on achieving content knowledge in biochemistry, with the intent of encouraging students to apply them in healthcare. The report of Silva and Batista (2003), for example, revealed that biochemistry education in the health sciences is centered on biochemistry content. In another study, the concept of intermolecular forces, physical properties, acid–base chemistry, equilibrium, and chemical reactions were the main focus of Schroeder et al. (2017) in teaching biochemistry concepts in a healthcare context.

Similarly, non-science major students were taught with biochemistry concepts such as molecular structures, chemical reactions, chemical equilibria, kinetics and other chemistry content by embedding them in module activities in nutrition, diagnostics and medicine (Armstrong & Poe, 2020). Other studies have also utilized biochemistry instruction to increase generic (non-chemistry) critical thinking skills and biochemistry content knowledge (Goeden et al., 2015).

One issue that has not been addressed by these studies is the likelihood of retention of biochemistry concepts and their application in other related health contexts. Clearly, biochemistry content, when taught using health contexts, require prior knowledge of physiology, pharmacology and cellular biology coupled with a mindset that *in vitro* chemical environments are different from *in vivo* systems (Jacob, 2002). Furthermore, the increase in knowledge of biochemistry concepts may only be true for the health contexts these studies have presented, but may be limited or not applicable in other contexts. In these studies, an increase in conceptual understanding was often reported as successful, but an improvement needs to be categorized whether it was clarification of misconceptions or enhancement of prior knowledge.

In contrast, biochemistry education has also been reported to promote scientific literacy in the context of civic and consumer roles. For instance, Taylor (2019) used real-life socio-scientific issues related to health such as relationship of proteins and weight loss, health effects of a diet plan, analysis of genetically modified organisms, or evaluation of scientific literature in biochemistry. However, such an approach requires complete evaluation of the presented biochemistry and health-related information.

These aforementioned studies, if utilized in the Philippine setting, may pose more problems as biochemistry is only offered for one semester, and all biochemistry concepts are crammed in a one-hour lecture period and two-hour laboratory period. A further dilemma is the selection of appropriate health contexts to prepare students in their professional subjects, because health concerns in the Philippines are different from the international setting, and these vary even in rural and urban areas.

If the approach in biochemistry education becomes more polarized to health contexts, students may generally give generalized conclusions based on incorrect heuristics. If the focus is more focused on content knowledge, students may not translate the concepts as relevant to health concepts. Clearly, the merging of biochemistry concepts and their health contexts needs to be carefully designed to enhance content knowledge and its application to health concepts.

## Literature Gaps Related to the Study

The propensity of utilizing *structure-property* and *structure-function* relationship in teaching biochemistry to health science students is supported by the need to improve content knowledge and conceptual understanding However, studies in biochemistry education do not further elaborate how biochemistry education leads to skills relevant in addressing health outcomes such as improved health literacy, decreased mortality and morbidity.

This goes back again to the issue on teaching biochemistry to health science students. As a chemistry subject, it is expected that health science students learn chemistry contexts. But health science students study biochemistry not to become biochemists nor biochemistry researchers. Biochemistry education in health sciences, therefore, is a unique case as it focuses on biochemistry contexts related to health. A critical balance between content and health context seems to be unaddressed in literature.

Often, content knowledge in chemistry easily becomes forgotten in the health science programs, unless, students a deeper approach of learning is adopted.

However, even health science students with deep conceptual understanding of biochemistry may still prefer to use a surface learning approach (Minasian-Batmanian et al., 2005). So far, this has not been validated by other related studies as health science students often learn health concepts by integrating various science and health-related concepts. In addition, Minasian-Batmanian et al. (2006) reported that learning complex biochemistry topics are often approached by health science students using surface learning, despite having used a deep learning approach previously.

These reports suggest that the learning process utilized by health science students is only utilized to pass the subject, not to use biochemistry knowledge to decrease health gaps, improve health literacy among patients, and achieve health national outcomes. These issues remain unaddressed because most studies related to biochemistry education in health science programs only emphasized learning biochemistry content knowledge through health contexts (Armstrong & Poe, 2020; Brown et al., 2018; Clark et al., 2019; Fernandez, 2015; Goeden et al., 2015).

This brings us to the argument that probably, an increase in biochemistry content knowledge is not the goal of effective biochemistry education in health sciences, but a means to achieve the required professional competencies of health science students – to communicate biochemistry knowledge, educate patients and promote health literacy. This brings us to the proposed competencies that students may need to achieve this goal: chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy. Hence, a thinking process spanning from biochemistry to actual health issues, is proposed. This is the reason why mereology-based instruction, or the use of *part-whole* relationship, is proposed in teaching biochemistry.

## Causes of Failure to Link Biochemistry and Health

Biochemistry education needs to be directly applied to health concepts because health interventions and health decisions involve biochemistry concepts, more than general inorganic chemistry or organic chemistry content. However, the review of literature has revealed that health science students face several difficulties applying biochemistry concepts to health-related concepts. This section reviews the possible reasons for the failure of health science students in linking biochemistry concepts to health concepts.

### Poor understanding of visual representations

The first reason related to the failure to link biochemistry concepts to health concepts is related to the inability of health science students in understanding the nature and limitations of visual representations. In the health science programs, biochemistry education involves studying visual representations such as molecular models, molecular structures, electronic potential maps and diagrams. In most topics in the health sciences, visual representations are used to address the sub-microscopic and the symbolic dimensions to explain the macroscopic observations.

For example, molecular models are commonly used to explain the biochemical concepts related to health (Azzalis et al., 2012; Edginton et al., 2013; Minasian-Batmanian et al., 2006; Novelli & Fernandes, 2007). Representations, on the other hand, are used to explain molecular features and properties. For example, visual representations (models and visualizations) are commonly used to describe structural features and properties of molecules (Harle & Towns, 2013; Harris et al., 2009; Li & Koehl, 2014) and molecular interactions or dynamic processes (Bussey & Orgill, 2015).

Failure to understand the nature of biochemistry models and representations may be attributed to difficulties experienced when interpreting a model or focusing on superficial details of the representation. Cooper and Oliver-Hoyo (2017) reported that the models for macromolecules are difficult for students to interpret due to a high degree of complexity of the molecules and the need to address electrostatic and non-covalent interactions in the molecule to describe its features and properties. Unlike simple molecules, the macromolecules which are commonly studied in biochemistry are more complex and may require several layers of chemical concepts.

Forbes-Lorman et al. (2016) criticized that some models used in teaching molecules were promoting "deceptive clarity" which leads to superficial understanding of molecular features and properties. This may potentially confuse students because representations only present selected features of the molecule that is illustrated within the limitations of the materials used to construct the representation. Cooper and Oliver-Hoyo (2017) reported that students struggled in applying the principles of polarity to larger areas related to hydrophobic collapse and protein solubility. Hence, if students do not possess an ability to apply their inferences on the basic property of the molecule in explaining the features of the macromolecule, then confusion may arise.

In addition, most biochemistry instructors mistakenly assume that students already possess visual literacy when presented with visual representations (Linenberger & Holme, 2014). Hence, learners with low prior knowledge on visual representations do not benefit from learning biochemistry using representations. Since chemical reasoning in biochemistry depends on a student's ability to understand models and representations, failure to interpret molecular structures and properties from models and representations may ultimately lead to misconceptions.

## Limited Scope and Depth of Biochemistry Content in Health Science Education

The scope and depth of biochemistry concepts in the health sciences are often presented as too simplified and prescriptive, without considering the nature of chemical environments. Since biochemistry concepts are relevant to health science education (Minasian & Batmanian, 2006; Sadi, 2013; Vittal & Jaweed, 2015), it is important to emphasize the role of molecular structure to its properties and roles in the body.

In the Philippines, Fernandez (2012) stressed the importance of biochemistry to freshmen BS Nursing students in the context of pharmacology, nutrition and pathophysiology. These three subjects, in reality, deal with complex concepts which address the need for integrating chemistry concepts with physiology and metabolism. A simplified discussion could lead to dumbing down of concepts, which may lead to misunderstanding of the concept and erroneous interpretation.

Laboratory data should be used to infer possible biological roles or functions in living organisms. As argued above, the biochemistry concepts in the health sciences focus more on the relevance of the chemistry concepts to health (Erasmus, et al., 2014; Jiao et al, 2014; Peacock & Grande, 2015), but do not emphasize the application of inferences from laboratory *in vitro* or *in vivo* data to health.

In addition, the concepts of basic instrumentation such as spectrophotometry and polarimetry are commonly integrated with laboratory experiments and research to interpret laboratory results (Ciancaglini et al., 2001; Powers et al., 2007). However, the context of the discussions in these aforementioned studies is related to inferring the health implications of results, not on the concept related to the analytical methods in spectrophotometry or polarimetry. Students need to understand the principles involved in specific instrumentation methods in the laboratory setting to generate correct inferences because *in vitro* laboratory settings cannot fully capture the complexity of *in vivo* systems.

## Heuristic reasoning

The biochemistry subject in health science programs does not address the actual biochemistry concepts essential for professional practices in the health sciences. Due to the diverse scope and depth of biochemistry in the health sciences, health science students often resort to simplifying chemistry concepts using heuristic reasoning. In the context of chemistry education, heuristic reasoning involves shortcut reasoning strategies to solve particular tasks, but may cause errors in judgment towards choosing a correct answer or making inferences (Talanquer, 2014). However, health concepts are dynamic and may require a skillful navigation and utilization of appropriate chemistry concepts to justify health decisions. Over-simplifying concepts into a set of rules promotes incorrect associations and inferences among health science students, leading to poor health-related learning outcomes.

This is further aggravated by the limited amount of time allotted to learn complex topics. In the Philippines, biochemistry is offered for one semester only for students in (mention the courses here). Concept simplification in biochemistry may be problematic because the dynamic nature of metabolic processes is difficult to capture using only a few biochemistry concepts. Simplifying biochemistry information into rules or simple algorithms may promote a hasty utilization of automaticity of reasoning, which is counterproductive to the critical thinking-based activities designed for health science programs.

Heuristic reasoning is used when interpreting biochemical literature and inferring results of laboratory experimentation. For example, Coleman et al. (2015) reported that students often conclude that correlation of variables in biochemistry literature can be used to prove causation. It is also a common practice to use *in vitro* studies to explain or infer physiologic roles or *in vivo* properties or functions of biomolecules (Ciancaglini et al., 2001; Dean, 2002; Duxbury, 2004; Harle & Towns, 2012; Jiao et al., 2014). However, such practice may promote generation of poorly supported health-related inferences because the chemical environment in laboratory settings is different to the chemical environment in cells (Jacob, 2002). Concept simplification is also influenced by too much focus on declarative chemistry knowledge in the health sciences without applying them in various contexts of health.

The need for critical reasoning that can guide the capacity to search, analyze, assess and synthesize information was articulated in the Philippine education system through Executive Order No. 83 and CHED Memorandum Order No. 46 (Sana et al., 2015). In the Philippine higher education curriculum for health science programs, it was emphasized that the health data or information should be 'evidence-based'. Simplifying concepts and preference to heuristic reasoning promotes poor chemistry reasoning and uncritical analysis of health information.

## Roles of Chemical Identity Thinking in Health

Chemical identity thinking is one of the competencies crucial in linking biochemistry to health. The term chemical identity was described by Ngai and Sevian (2017) as an "*attribute of a substance which makes it different from other* *substances.*" As stated in the study of Ngai (2017), chemical identity thinking requires knowledge, reasoning and skills necessary to classify substances (p.13). As a part of the chemical thinking framework, chemical identity thinking is concerned with answering the question "*what is this substance*" (Banks et al., 2015; Ngai & Sevian, 2017).

Chemical identity thinking follows a progression or sophistication of reasoning, from *objectivization*, *principlism*, *compositionism* and *interactionism* (Ngai, 2017). The most advanced level of chemical identity thinking (*interactionism*) relates well to the analysis of molecular interactions to describe the properties of substances. Such mindset is also related to thinking about properties of substances such as boiling point, viscosity, and polarity as emergent from interactions of molecules comprising the substance (Sevian & Talanquer, 2014; Talanquer, 2018).

In the curriculum for health sciences in the Philippines, chemical identity thinking is seemingly evident when bulk samples are involved. For example, pharmaceutical agents are often classified based on functions (i.e., *antibacterial, antifungal, antiviral*), and is classified as an *objectivization* chemical identity thinking based on the classification of Ngai and Sevian (2017). Similarly, intravenous fluids are classified as *isotonic, hypotonic* or *hypertonic* solutions. Differentiating substances based on emergent properties are more difficult since it involves analysis on how molecules interact and contribute to the emergent property.

It is uncommon for health science students to use concentration or boiling points to differentiate intravenous fluids, nor use chemical information such as acidity or reducing property to differentiate foodstuff or medications. Similarly, advice on nutrition and diet modification is approached based on absorbed nutrients and health effects, not too much on molecular composition and interactions. Based on their role in health contexts, substances and materials are often understood alongside their health effects, and chemistry concepts are seemingly set aside. But it has to be emphasized that biological systems are complex, and the chemical environment also has its own set of emergent properties (van Regenmortel, 2004). These emergent properties include the buffering activity of blood plasma, maintenance of negative action potential via active transport, and osmotic regulation between intravascular and interstitial spaces.

However, a more advanced chemical identity thinking such as *compositionism* or *interactionism* is necessary if health science students need to explain why pure alcohol cannot be used as rubbing alcohol, or why a fruit wine cannot be substitutes for rubbing alcohol. In these contexts, the function (as an antiseptic or disinfectant) is dependent on concentration and interaction with other components such as water or plant metabolites and sugar. Similar arguments can also be said why vinegar cannot be a substitute for glacial acetic acid in the laboratory, nor can glacial acetic acid be a substitute for cooking *adobo*.

Unfortunately, the role of chemical identity thinking is not explored in the literature involving biochemistry and health, despite its perceived importance in enhancing the thinking process of students to apply biochemistry concepts to the context of health. Even in the Philippine setting, there is no literature exploring how health science students differentiate substances or materials using chemical identity thinking.

## Critical Thinking in Chemistry

Chemical identity thinking plays a significant role when students analyze problems in chemistry. A correct understanding of chemical identity allows a student to apply or use the information related to a substance, such as physical properties and chemical reactivities when performing laboratory activities, explaining chemical reactions, and inferring possible results from chemical reactions. Thus, chemical identity thinking is essential in critical thinking tasks in chemistry.

Critical thinking is ubiquitous in chemistry education studies. However, critical thinking has been defined differently, and studies have claimed it as generic and transferable, while other studies consider it a s context-specific (Willingham, 2008). Some studies also report it as a measurable construct after an intervention and raw scores in an instrument, or a self-report of improvement commonly used, although other studies claim that it increases even without teaching interventions (Solon, 2007, as cited in Stephenson & Sadler-McKnight, 2016).

The definition of critical thinking becomes even fuzzier when health professional education contexts are incorporated. Kahlke and Eva (2018) classified critical thinking as either biomedical, humanist or social justice-oriented, which are again, more context-specific than generic. There is no consensus definition of critical thinking in chemistry and Facione's definition of critical thinking does not capture the required mental characteristics of critical thinking in chemistry. Thus, the researcher used "critical thinking in chemistry" to emphasize that critical thinking is context-specific. *Critical thinking in chemistry* has been adopted as a context-specific competency expected from health science students when chemistry instruction is involved.

In this study, the construct *critical thinking in chemistry* was thought of based on previous working definitions within a chemistry context. The working definition of critical thinking by Ennis (1989) was a "*reasonably reflective thinking that is focused on deciding what to believe or do.*" Oliver-Hoyo (2003) also defined critical thinking as "*intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information.*" However, these skills which represent critical thinking in chemistry were meant to be applied in a written report.

While it is recognized that there are general thinking skills related to critical thinking, a context-specific critical thinking in chemistry is based on "*how professional chemists think,*" a notion which is supported by Garrat et al. (2000). Based on their study, thinking like a professional chemist includes the following skills: *analyzing and evaluating arguments, making judgment, retrieving information* and *experimenting*. It has been emphasized that critical thinking needs to be explicitly instructed to increase critical thinking skills (Bensley et al., 2010).

Despite criticisms on analysis of arguments as a form of reduction of critical thinking (Govier, 1989), argumentation was used as an activity in other studies to improve critical thinking (Bensley et al., 2010; Jacob, 2004). Despite the notion that critical thinking is not captured completely during argument analysis, the present study supports that critical thinking can be measured in arguments as it still involves analysis and interpretation of data, and refinement, development and use of models (Rodriguez & Towns, 2018).

Another issue is the measurement of critical thinking, as most studies used changes in raw scores or critical thinking indicators. Most studies dealing with critical thinking in chemistry assessed improvement of critical thinking by interpreting changes in raw scores in either context-specific (Gupta et al., 2014; Jacob, 2004; Oliver-Hoyo, 2003) or generic contexts (Chase et al., 2017; Espinosa et al., 2013; Stephenson & Sadler-McKnight, 2016).

Jacob (2004) used raw scores and measured context-specific critical thinking when evaluating arguments in chemistry by using the ability of students to assess statements, decide on the logical validity of statements, and communicate the reason for the decision. On the other hand, raw scores from rubric were used by Oliver-Hoyo, (2003) and Gupta et al. (2014) to evaluate critical thinking in written reports. While the measurements are context-specific, the utilization of written reports may only reflect changes in thinking process but not skills in actual practices.

In the study of Chase et al. (2017), critical thinking was assumed to be transferable or generic, as a validated research instrument (Critical-thinking Assessment test) was used. Similarly, Stephenson & Sadler-McKnight (2016) and Espinosa et al. (2013) also assumed critical thinking as generic and transferable when they used the California Critical Thinking Skills Test after an intervention in chemistry education. Using changes in raw scores are based on the assumption that changes in scores reflect changes in thinking process, but raw scores were reported to be non-linear (Boone & Noltemeyer, 2017). Changes in raw scores in pretest-posttest design may imply different interpretations depending on which item was correctly answered during posttest (Nitta & Aiba, 2019). Hence, inferences on differences in raw score need to be carefully interpreted.

Whether critical thinking is generic or transferable, it is acknowledged that critical thinking in chemistry may improve in other biochemistry subjects. If general inorganic and organic chemistry concepts prepare students for biochemistry in the health sciences, then, perhaps biochemistry instruction also enhances the conceptual understanding of general inorganic and organic chemistry concepts, thereby emphasizing that critical thinking in chemistry is context-specific but transferable to a related chemistry context.

## Chemistry-based Health Literacy

Chemistry-based health literacy, the construct which is investigated in this study, is based on linking appropriate chemistry concepts within a socio-scientific context. Socio-scientific issues have been addressed in chemistry education in previous studies and topics in nanotechnology (Jones et al., 2014), climate change (Eggert et al., 2016; Flener-Lovitt, 2014), role of phosphate in eutrophication (Zowada et al., 2019), and biofuels (Dishadewi et al., 2020) have been explored. It is evident in literature that efforts have been made to address health-related topics in chemistry such as acid-base concepts (Brown et al., 2018; Schroeder et al., 2017), organic functional groups (Clark et al., 2019), and diverse chemistry topics such as intermolecular forces, physical properties, equilibrium and chemical reactions (Schroeder et al., 2017), but these efforts were designed to increase conceptual understanding, not to enhance the applications to socio-scientific issues.

A review of the article of Genyea and Callewaert (1983) reveals that the curriculum of health science students should focus on *basic chemistry and aim to increase their reasoning ability and problem-solving skills*. The topics suggested for basic chemistry include bonding, intermolecular interactions, solutions and colloids, thermodynamics, kinetics, chemical equilibrium, oxidation-reduction, and acids and bases. However, for health-related subjects like biochemistry, the concepts of thermodynamics, kinetics, chemical equilibrium and redox reactions should focus on qualitative concepts. For example, Genyea and Callewaert (1983) stated that a qualitative concept for a chemical reaction can focus on the notion that total amount of energy released is the same no matter how the reaction is carried out, but for different reaction conditions, the energy can be released in different forms. For a qualitative concept related to kinetics, students can also be taught to appreciate how a catalyst can alter the rate of a reaction by changing the reaction mechanism.

Recent literature in biochemistry education in the context of health has relied on the analysis of functional groups to results of urinalysis (Clark et al., 2019). Furthermore, functional group analysis of biomolecules was emphasized to be relevant in this age of genome (Brenner, 2013). Macromolecular structure, enzyme function, and central carbon metabolism was also regarded as a focus of biochemistry for premedical students (Brenner, 2013) since not all topics can be covered in one semester. Currently, health science students are required to have adequate depth of both chemistry-related topics and human biology topics. This is also supported in the health profession, as critical thinking involves clinical reasoning and human welfare (Kahlke & Eva, 2018).

It is asserted in this study that adequate chemistry knowledge plays a role in developing health literacy. Health is a socio-scientific issue, and other studies have utilized socio-scientific issues to teach science content (Dishadewi et al., 2020; Flenner-Lovitt, 2014; Sadler et al., 2016; Zowada et al., 2019), critical thinking and chemical literacy (Rahayu, 2019). This study is more similar to the study of Eggert et al. (2016), which focused on using a teaching strategy (*computer-based concept mapping scaffolds*) to enhance socio-scientific reasoning, and that of Owens et al. (2020), where they focused on teaching the importance of water and how to use the concepts in hydrology, water policy, history and urban water management in reasoning related to socio-hydrologic issues.

The need to address chemistry-based health literacy is based on a report that health literacy of Filipinos is generally low. In fact, Filipino adolescents were reported to have low to very low health literacy (Javier et al., 2019). Furthermore, misinformation and pseudoscience are common in nutrition and dietetics (Neale & Tapsell, 2019) and medicine (Pray, 2006) to which Filipinos are prone to easily accept. Disease causation in the Philippines is also attributed to cultural beliefs such as superstition, mysticism or "*God's will*" (Abad et al., 2014). Filipinos also focus too much on curative interventions and the current setting shows the inequality of healthcare services in rural and in urban areas. These factors compete with the acceptance and understanding of science concepts and influence how Filipinos achieve health literacy.

Several studies on health literacy are based on the assessment of an individual's self-belief on their ability to access adequate and correct health information, understand information or navigate through the health care system (Abel et al., 2014; Duong et al., 2017; Hawkins et al., 2014; Mullan et al., 2017). In these studies, scientific principles are not used as pieces of evidence to support a health decision. This is problematic and ironic in the health science programs, where chemistry and other science subjects are designed to improve understanding of health concepts. Unfortunately, studies on increasing health literacy by using chemistry contexts are not common in both international and local contexts, and this makes this study interesting.

While it is important to teach content in biochemistry, this study also credits the importance of using a *thinking process* when learning biochemistry concepts. Using a thinking process in learning content knowledge posits the application of the process to various topics, allowing students to learn concepts on their own, while the biochemistry teacher provides scaffolding on conceptual understanding and its application to other related contexts. Hence, chemistry-based health literacy is the last construct which is measured in this study.

## Theories Related to Mereology-based Instruction

The theoretical framework of this study is related to Action-based Model of the Cognitive Dissonance Theory, Cognitive Load Theory and Situated Learning Theory. According to the action-based model of the cognitive dissonance theory, perceptions and cognitions drive people to act in specific ways. The conflict in perceptions and cognitions experienced by an individual may lead to the resolution of needs that elicit behavior which reduces the feeling of dissonance (Harmon-Jones et al., 2015). This theory is related to health literacy and how mereology-based instruction addresses it. Health literacy is affected by multiple factors, and content knowledge is one of these. It is hypothesized that if cognitive dissonance is felt when learning biochemistry concept using mereology-based instruction, then students need to refine their chemical identity thinking, critical thinking in chemistry and evaluation of false reductionism in biochemistry. Furthermore, if biochemistry content knowledge provides additional thought to influence health literacy, then students will learn biochemistry content more.

According to the cognitive load theory, learning is hampered when working memory capacity is exceeded in a learning task. De Jong (2010) explained that the total cognitive load is a sum of *intrinsic* cognitive load (inherent characteristics of the material to be learned), *extraneous* cognitive load (load caused by the instructional material used to present the content) and *germane* cognitive load (load imposed by the learning process). Generally, a key characteristic of presenting a difficult concept is to prevent overloading of the learning working memory (Goldman, 2003).

Mereology-based instruction utilizes argumentation and QSAR activities, which are high in *intrinsic*, *extraneous* and *germane* cognitive load. However, it is hypothesized that immersing students in activities with adequate cognitive load is also relevant in influencing their thinking process.

Lastly, Situated Learning Theory states that knowledge is not easily absorbed when learned out of context for use elsewhere when a particular situation demands it (Lave, 1988). Mereology-based instruction is based on the recognition of reductionist *part-whole* relationship in biochemistry and in health concepts using ontological and biochemistry knowledge and apply them to address health literacy. Clearly, biochemistry in health science programs is an authentic context in which biochemistry can be learned via health concepts and health literacy can be addressed by learning biochemistry concepts.

## The Thinking Process in Mereology-based Instruction

Based on the gathered literature, using mereology-based instruction can address the three constructs which were identified as crucial in the health science programs: chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy. The hypothesized thinking process after mereology-based instruction is shown in Figure 2.1.

When biochemistry concepts are presented using a part-whole relationship theme, students need to understand the biochemistry context where the part-whole relationship is applied, and the ontological nature on how the part-whole relationship in the identified biochemistry context is presented. For example, choosing a substance as a "whole" and molecules as "parts" need to be evaluated whether the attributes of the identified "part" is similar or different to the attribute of the identified "whole." Other part-whole relationships can also be explored in the following contexts: "active ingredient" (part) of a product (whole), substance (part) present in a mixture (whole) or monomer (part) as a building block of a polymer (whole). The part-whole theme can be presented with a fallacy or chemistry evidence which describes the property of the identified "part" and the property of the "whole" to engage student thinking.

When students are presented with the aforementioned information, students will be engaged to recall the chemical identity of a substance, apply critical thinking about the presented chemistry evidence, and evaluate the claim in the identified health context. Furthermore, health literacy is addressed as students will include other sources of evidence such as related science concepts, health concepts, sociocultural contexts, and sociodemographic contexts to critically evaluate the presented part-whole relationship. The thinking process becomes cohesive to the context of biochemistry which has high relevance to the health science programs.

Mereology-based instruction is meant to address the evaluation of false reductionist claims using *part-whole* relationship. Biochemistry concepts are abundant in reductionist claims based on incorrect heuristic reasoning. Hence, this study reinforces the claim that chemical data needs to be evaluated carefully (Coleman et al., 2015; Letchford et al., 2017; Ferenc et al., 2018) and treated with skepticism because different interpretations laden with fallacies may be present (Harré, 2014).

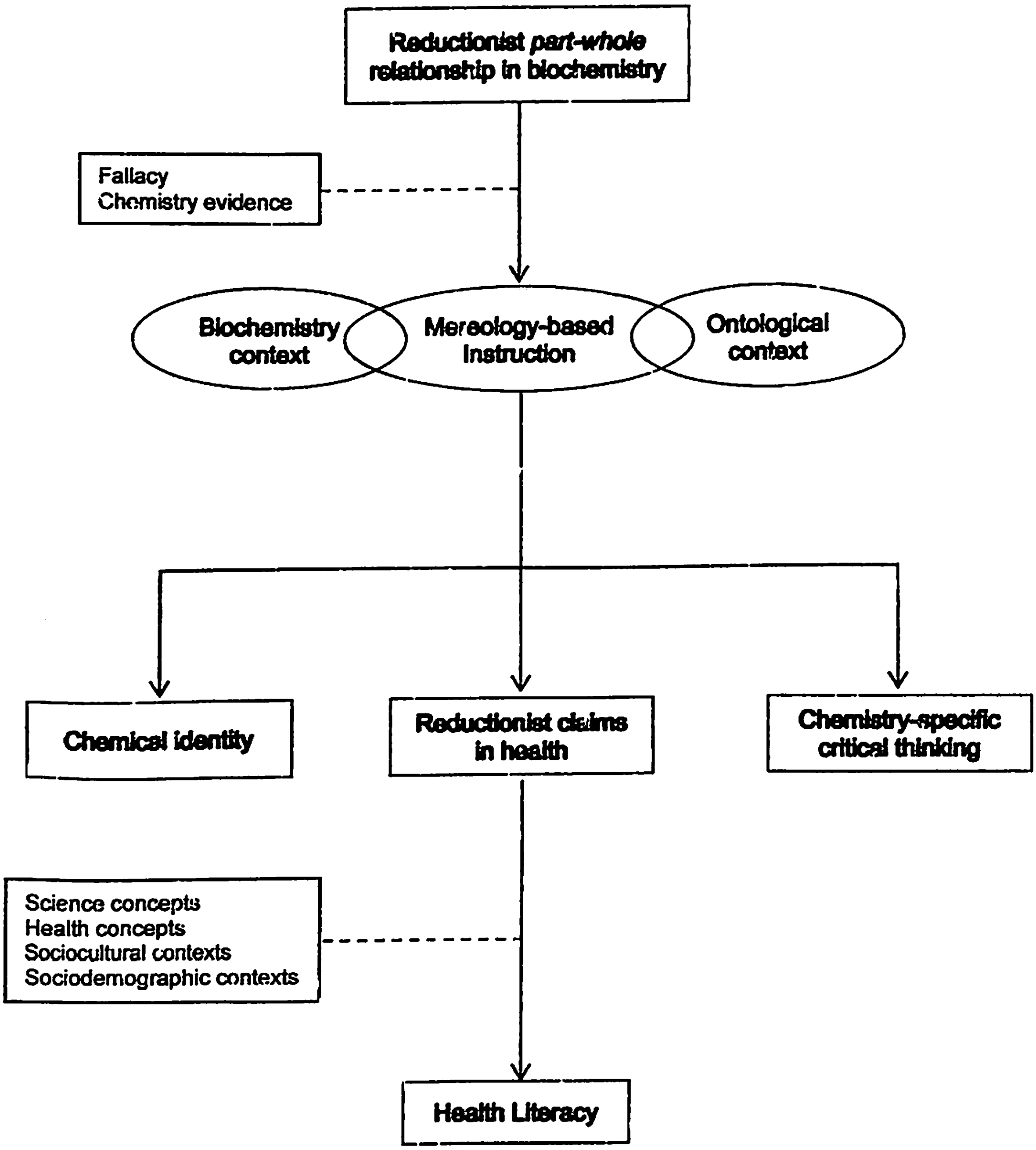


*Figure 2.1.* Hypothesized thinking process as a result of mereology-based instruction

## Mereology-based Instruction – A Proposed Intervention

This section provides the rationale why mereology-based instruction is proposed to be used in teaching biochemistry. It should be clarified though that this type of instruction does not aim to use mereology to teach content knowledge. This type of instruction uses false reductionist *part-whole* relationship in biochemistry that provides opportunities for modifying students' thinking process and use the same thinking process to increase chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy.

A false reductionist part-whole relationship is exhibited when the attributes of a "part" is automatically used to justify the attributes of a "whole." Consider for example, the attribution of radical scavenging property of vitamin C to a product. If a product contains a substance which exhibits a property, several factors need to be considered such as the method of preparation and stability of the substance. For example, fruit jams, which are made from fruits, may be inaccurately claimed to exhibit radical scavenging properties just because fruit extracts are reported to exhibit radical-scavenging properties. In this example, the method of preparation destroys the stability of radical-scavenging molecules found in fruit. Hence, the part-whole relationship is false, and attributing the property of the fruit to be present in the product is an erroneous and reductive claim. The same fallacy can also be observed when discussing natural products, using pieces of evidence from laboratory assays or animal studies as basis for the choice of medication or food.

It is claimed that the properties of materials are due to molecular interactions (Talanquer, 2007). If part-whole relationships were to be involved, it is logical to claim that the interaction of the components of a sample mixture or substance manifests as a property of that sample. The *part-whole* relationship is obvious as the parts refer to the components, and the whole refers to the sample. Mereology is relevant to the present study because the '*part*' can be assigned to various concepts in biochemistry and in health-related subjects.

Mereology-based instruction is based on mereology, which involves the study of the relationship of a '*part*' to a '*whole*' or a '*part*' to a '*part*' within a '*whole*' (Harré, 2014; Gruszczyński & Varzi, 2015; Needham, 2012). Mereology has been discussed extensively in the philosophy of chemistry (Ghibaudi & Cerruti, 2017; Harré, 2014), although the contextualization of mereology in chemistry is still being refined. Mereology is relevant to the present study because the 'part' can be assigned to various concepts in biochemistry and in health-related subjects. In this study, there are two goals addressed in terms of studying part-whole relationships: identification of '*part*' and 'whole' and analysis whether the property or function of the '*part*' is attributable to the '*whole.*'

## Components of Mereology-based Instruction

Two learning activities were selected to comprise the mereology-based instruction. These activities are argumentation and quantitative structure-activity relationship (QSAR) laboratory activities because of the opportunities to teach, refine and provide feedback to the thought process of students when they engage in argumentation and laboratory activities. According to Butler et al., (2013), explanation feedback is better than correct answer feedback for promoting transfer of learning.

Pabuccu and Erduran (2017) stated that argumentation can wean students from rote learning at the university level. Tümay (2016) also remarked that argumentation is a scaffold to enhance students' understanding of 'emergent' properties of substances. On the other hand, quantitative structure-activity relationship (QSAR) studies involve the correlation of physicochemical (independent) properties and biological (dependent) activity of bioactive molecules (Mahobia et al., 2014). Argumentation and QSAR activities provide enough student engagement and honing of their thinking process so that they could choose pieces of evidence in their argumentation activities.

## Intervening Variables

In this section, the factors which may affect the effectiveness of mereology-based instruction in chemical identity thinking, critical thinking and chemistry-based health literacy are discussed. These factors include cognitive load, prior knowledge of chemistry, prior knowledge of visual representations and gender.

### Cognitive Load

It is important to address cognitive load when introducing an approach in teaching biochemistry because different chemistry activities such as problem solving, analogy, interpretation of visual representations and analogical reasoning have varied types of *extraneous* and *germane* cognitive loads. In this study, mereology-based instruction includes argumentation, quantitative structure-activity relationship *in silico* activities and biochemistry information appraisal. In the studies of Behmke and Atwood (2013) and Milenkovic et al. (2014), decreasing cognitive load can improve acquisition of chemistry knowledge. Furthermore, students may not immediately respond to a type of instruction and may initially use surface learning (Jones et al., 2014).

Students may experience cognitive load while performing mereology-based instruction activities such as argumentation and quantitative structure-activity relationship activities. Cognitive load may either encourage or discourage students in learning biochemistry concepts independently. It is therefore important to determine the types of cognitive loads experienced by the students and investigate which cognitive load component needs to be modified to ensure learning. Determining the cognitive loads in different activities can also aid in the modification of mereology-based instruction and to avoid overwhelming the students with unnecessary tasks.

## Prior Knowledge of Chemistry Concepts

The prior conceptual understanding of chemistry concepts influences the trajectory of the learning gains of health science students. Compared to novice learners, expert learners utilize mental representations and apply their knowledge to classify problems and solve them accordingly (Kozma et al., 2000). Expert learners navigate the relationship of the macroscopic, sub-microscopic and symbolic domains of chemical representations while novice learners tend to focus on "surface features" (Kozma, 2003). Goldman (2003) argued that the real competency of an expert student, regardless of the complexity of the concepts being learned, is the ability to select, organize and integrate concepts.

Prior knowledge in chemistry also influences how students perceive the role of visual representations in learning chemical concepts. The effectiveness of chemical representations in promoting learning of new concepts in biochemistry also differs between novice and expert learners. Prior chemistry knowledge was chosen as an intervening variable in this study because novice and expert chemistry learners are expected to exhibit different progression of conceptual understanding of mereology in biochemistry. Coppola and Krajcik (2013) described that a secondary level chemistry focuses on multiple topics while tertiary level chemistry is specialized, focusing on interrelated topics. However, prior chemistry concepts which were learned in high school are important in learning tertiary level chemistry subjects.

Prior chemistry learning may also influence the differences in the ability of students to interpret visual representations, to perform *in silico* and in vitro laboratory activities, and to choose the correct chemistry concepts during argumentation. Lastly, prior chemistry knowledge may influence the ability of students to utilize chemistry concepts in supporting health decisions.

## Prior Knowledge of Visual Representations

Mereology-based instruction requires the analysis of visual representations particularly skeletal structures of simple molecules when performing quantitative structure-activity relationship. The effectivity of the intervention will be influenced by the prior knowledge of health science students regarding visual representations. Visual representations also help explain intermolecular and intramolecular interactions in simple and complex biomacromolecules.

As discussed earlier in this chapter, visual representations aid in providing details on structure and properties of molecules (Harle & Towns, 2013; Harris et al., 2009; Herman et al., 2006). Similarly, when students perform simple quantitative structure-activity relationships in mereology-based instruction, they need to interpret molecular structures and how they are understood to construct relationships based on analysis of molecular properties. It is important to determine prior knowledge of visual representations because it determines whether students know how to infer molecular properties and molecular interactions based on analysis of molecular structures.

Most biochemistry teachers mistakenly assume that students already possessed visual literacy upon presenting visual representations (Linenberger & Holme, 2014). Furthermore, analysis of skeletal formula does not involve explicit molecular properties and three-dimensional features, that students may over-simplify when making inferences. Forbes-Lorman et al. (2016) criticized that some visual representations such as models used in teaching molecules were promoting "deceptive clarity" which leads to superficial understanding of molecular features and properties. Similarly, skeletal models may exhibit deceptive clarity, while in reality, it should be analyzed concurrently with other visual representations.

### Gender

The differences in the learning gains and chemistry achievement of male and female students have been investigated in several studies. It is asserted in this study that the effectivity of mereology-based instruction may vary between males and females. Several studies have initially reported the differences in the abilities of male and female students in learning chemistry.

In the study of Forbes-Lorman et al. (2016), male students generally have higher performance in understanding structure-function relationship compare to females. However, hand-held physical models increased the performance of female students to levels which are equivalent to male students. Similarly, Rauschenberger and Sweeder (2010) also reported that female students generally have lower performance in Biochemistry compared to their male peers. In Malaysia, male students were also reported to have higher chemistry achievement than females (Veloo et al., 2015).

The difference in the performance of male and female students in chemistry has been linked to higher spatial literacy of male students compared to females (Forbes-Lorman et al., 2016). Studies have reported that male students generally have higher performance in chemistry than female students (Forbes-Lorman et al., 2016; Rauschenberger & Sweeder, 2010; Veloo et al., 2015). In other studies, female students were reported to exhibit more misconceptions in chemistry (Adesoji & Babatunde, 2008).

An important report emphasizing male and female student differences is their ability to organize information. Gulacar et al. (2019) reported that male students can organize information and build strong associations with chemistry-related concepts while female students do not form associations strongly. This will be relevant when determining the effects of mereology-based instruction to learning in biochemistry since health science programs are female-dominated, and the curriculum, assessment and evaluation might be gender-biased. Similarly, mereology-based instruction may pose the same bias if the activities involve visual representations and prior knowledge of chemistry concepts.

## Rasch Analysis in Chemistry Education Research

The Rasch model has been developed by George Rasch, a Danish mathematician. The Rasch model explains how a person's performance regarding a specific trait, can predict that person's response in a particular test item involving that trait (Boone & Scantlebury, 2006). In educational measurement, studies commonly use the classical test theory, in which raw scores are used to measure changes in student abilities. However, raw scores are not linear (Bond & Fox, 2007; Planinic et al., 2019), and the differences between any two consecutive raw scores cannot be assumed to represent equal intervals (Boone & Notelmeyer, 2017). The sum of raw scores cannot be used to compare student performance because item difficulties are different in research instruments (Boone, 2016). Subjecting non-linear measures to statistical tests also produce distorted results (Planinic et al., 2019).

Rasch theory serves as a guide in formulating an instrument which represents a range of "test-item difficulty" to its respondents (Boone, 2016). Through the use of Rasch analysis, validated instruments can be developed to evaluate the effectiveness of a curriculum and the learning progress of students (Herrmann-Abel et al., 2018). Furthermore, Rasch analysis methods can also be used for multiple choice tests, rating scales and tests, which are evaluated using a rubric. With these advantages, it is not surprising that several chemistry education studies have applied Rasch analysis.

A number of studies in chemistry education have utilized Rasch analysis for various purposes. Rasch models have been used in chemistry education to develop a scoring rubric (Deng & Wang, 2017; Grunert et al., 2013), measure understanding of chemistry concepts (Wei et al., 2012), develop concept inventories (Nedungadi et al., 2019) or evaluate the psychometric properties of an existing chemistry concept inventory (Barbera, 2013). In the Philippines, the study of Ferido et al. (2017) has applied Rasch analysis to determine the progression of learning in selected chemistry topics. In addition, Magno (2009) revealed that using Rasch analysis in analyzing results in a chemistry test resulted to less measurement errors compared to a classical test theory approach.

## Rasch Analysis Procedure

The Rasch model is used to construct an instrument which is good in agreement with the theory and basic requirements of objective measurement (Planinic et al., 2019). In addition, claiming that raw scores represent an objective measurement of the construct measured by a research instrument is inaccurate, as raw scores are nonlinear and the differences between raw scores cannot be assumed to represent equal intervals (Boone & Noltemeyer, 2017). Hence, raw scores do not accurately measure a person's actual ability in a particular construct underlying a research instrument. If science education researchers do not convert raw scores to a linear scale, an incorrect conclusion may be reached when using raw scores when using a parametric test (Boone & Scantlebury, 2006).

Rasch analysis was performed using the software Winsteps 4.4.5 using a dichotomous model for Prior Knowledge of Chemistry Concepts Test and Visual Representations Test while Rasch partial credit model was utilized for Chemical Identity Thinking Instrument, Critical Thinking Test in Chemistry, and Chemistry-based Health Literacy Test.

The model for dichotomous Rasch analysis takes the following form:

$$ln\left(\frac{P_{nik}}{1 - P_{nik}}\right) = B_n - D_{ik}$$

Where:

$P_{nik}$ = probability of n with ability $B_n$ responding at level *k* of item *i* successfully

$D_{ik}$ = difficulty of level k of item *i*, that is, the step or threshold for an examinee receiving score k instead of $k - 1$.

The partial credit Rasch model indicates that each item has its own rating scale structure. It is more appropriate for tests that have responses which can be given partial credit towards a correct response. The amount of partial correctness varies across items. The partial credit model is a version of the rating scale model and is described mathematically as:

$$ln\left(\frac{P_{nij}}{P_{ni(j-1)}}\right) = B_n - D_i - F_{ij}$$

Where:

$F_{ij}$ = threshold between categories *j* and $j - 1$ on item *i*.

In contrast to the rating scale model, the items of the same raw score can have different values of Rasch difficulties if the pattern of category usage on those items is different (Planinic et al., 2019).

The rating scale model was used for determining student ability logits in the cognitive load questionnaire. Mathematically, the rating scale model is represented by the equation:

$$ln\left(\frac{P_{nij}}{P_{ni(j-1)}}\right) = B_n - D_i - F_j$$

In this equation, *Fj* is the Rasch-Andrich threshold (step calibration), or the point on the latent variable where the probability of person n being observed in category j of item i equals the probability of the same person being observed in category *(j - 1)*. It has to be noted that *Fj* is estimated from the category frequency, and the difficulty of the item is now located at the point where the highest and the lowest categories are equally probable (Planinic et al., 2019).

## Conceptual Framework

The conceptual framework of the study is illustrated in Figure 2.2. In the framework, the dependent variables are chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy. The independent variable is the type of instruction, which is either mereology-based instruction or conventional instruction. The intervening variables in the framework are gender, prior conceptual understanding of chemistry concepts, prior knowledge of visual representations, gender, and cognitive load.

Prior conceptual understanding of chemistry concepts and prior knowledge of visual representations are grouped together as these chemistry-related variables areindicators of prior conceptual understanding of general inorganic and organic chemistry concepts prior to enrolling biochemistry. The variables gender and cognitive load are grouped together as these are non-chemistry related factors whichmay explain variations in chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy. Over-all, the variations in the intervening variablesmay influence the effectivity of mereology-based instruction in promoting the chemical identity thinking, critical thinking and chemistry-based health literacy of health science students.

It is hypothesized that mereology-based instruction builds on prior knowledge of chemistry and visual representation to improve the analysis of health-related contexts. It needs to be emphasized that mereology-based instruction in this study does not focus on teaching biochemistry knowledge using mereology but applying a thinking process in addressing false reductionist part-whole relationship in biochemistry and extend its premise to the context of health literacy.

The common theme used in conventional instruction is '*structure-property*' or '*structure-function*' relationship, although students are expected to fill the gap in relating the content knowledge to health applications. Mereology-based instruction utilizes a less familiar relationship of concepts with the hope of extending the conceptual knowledge gained to health contexts. The thinking process involved in mereology-based instruction may elicit chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy when students attempt to resolve chemistry concepts which cannot be confined in a part-whole relationship theme. Other sources of evidences may be obtained by students from both chemistry and health-related concepts to critically appraise the validity of a claim. Mereology-based instruction also engages students to recognize the limitations of part-whole relationship in health-related biochemistry topics which address health promotion, diagnosis of diseases and pharmacological approach of managing health problems. A reductionist part-whole relationship in chemistry presents a relevant cognitive dissonance and cognitive load which challenges the ontological nature of part-whole relationship and aligns the thinking process to falsify an illogical or erroneous simplification within a part-whole relationship theme. Hence, it is hypothesized that the learning process using mereology-based instruction addresses the expected competencies of health science students who have completed a one-semester biochemistry instruction. Lastly, it is hypothesized that a mereology-based instruction can address chemical identity thinking and critical thinking in chemistry synchronously with chemistry-based health literacy.

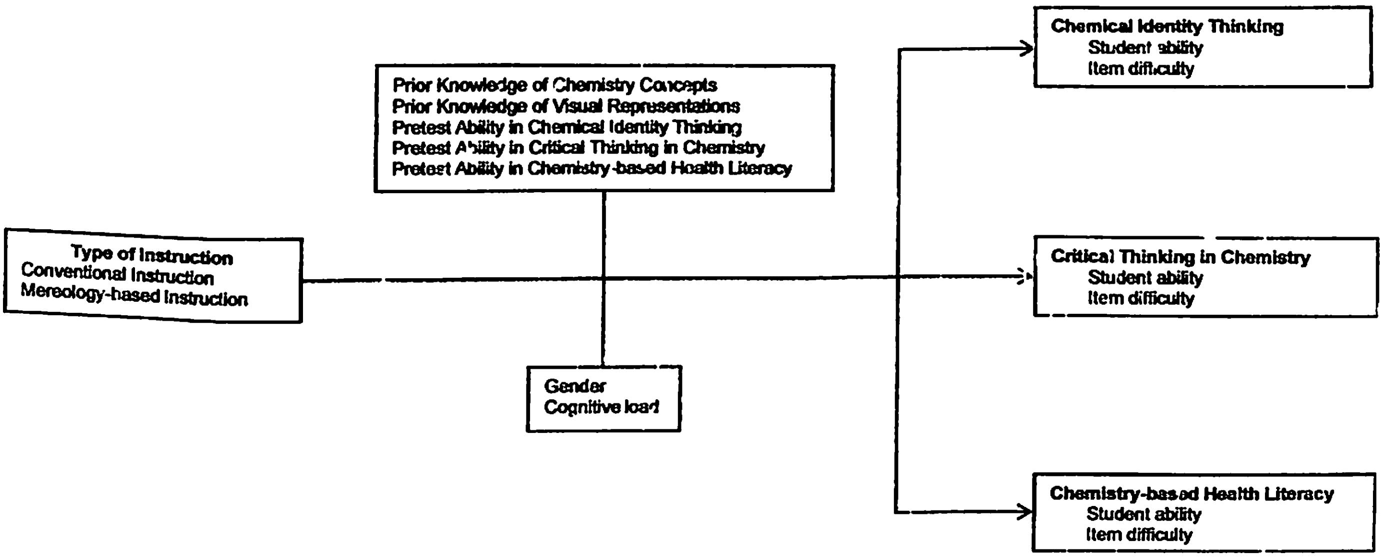


*Figure 2.2.* Conceptual framework of the study

## Hypotheses of the Study

In this study, it is hypothesized that mereology-based instruction in biochemistry will improve the chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy of students. The alternative statistical hypotheses are as follows:

1. The mean level of difficulty of items in prior knowledge in chemistry concepts and prior knowledge of visual representations in both mereology-based instruction and conventional instruction are higher than the mean student ability of participants.
2. After controlling for prior knowledge of chemistry concepts (PKCC) and prior knowledge of visual representations (PKVR), there is a significant difference between students exposed to mereology-based instruction (MBI) and to conventional instruction (CI) in terms of posttest chemical identity thinking, posttest critical thinking in chemistry and posttest chemistry-based health literacy.
3. Student ability in prior knowledge of chemistry concepts, student ability in prior knowledge of visual representations, mean total cognitive load, pretest student ability in chemical identity thinking and gender are significant predictors of posttest ability in chemical identity thinking in MBI and CI groups.
4. Student ability in prior knowledge of chemistry concepts, student ability in prior knowledge of visual representations, mean total cognitive load, pretest student ability in critical thinking in chemistry and gender are significant predictors of posttest ability in critical thinking in chemistry in MBI and CI groups.

5. Student ability in prior knowledge of chemistry concepts, student ability in prior knowledge of visual representations, mean total cognitive load, pretest student ability in chemistry-based health literacy and gender are significant predictors of posttest ability in chemistry-based health literacy in MBI and CI groups.

## Definition of Terms

Below is a list of the terms used in this study, and their corresponding operational definitions based on how they were used.

**Argumentation** is operationally defined as an activity involving syllogisms which are evaluated using Toulmin Argumentation Pattern.

**Chemical identity thinking** is operationally defined as the ability to differentiate two substances by virtue of a feature of property which is unique to these substances. Chemical identity thinking is measured as ability logit in chemical identity thinking instrument after performing Rasch partial credit model.

**Chemistry-based health literacy** is operationally defined as the ability to select correct health decisions and support it with contextualized chemistry-related explanations. Chemistry-based health literacy is measured as ability logit in the chemistry-based health literacy test after performing Rasch partial credit model.

**Cognitive load** is operationally defined as the difficulty experienced by students to mental or physical tasks related to the type of instruction. It is measured as the ability logit in cognitive load questionnaire after performing Rasch partial credit model using stacked analysis anchored on items.

**Conventional instruction** is operationally defined as the type of Biochemistry instruction involving *structure-property* relationship and *structure-function* relationship in argumentation and quantitative structure-activity relationship laboratory activities.

**Corrective effect** is operationally defined as an effect of type of intervention to elicit change in the ability of a negative logit (level 0) to a higher positive logit (level 1, level 2 or level 3).

**Critical thinking** pertains to critical thinking in chemistry, and is operationally defined as the ability to link correct inference and correct chemistry explanations in general inorganic chemistry and general organic chemistry. It is measured as the ability logit in critical thinking test in chemistry after performing Rasch partial credit model.

**Enhancement effect** is operationally defined as an effect of type of intervention to elicit change in the ability of a low positive logit (level 1 or 2) to a higher positive logit (Level 2 or Level 3).

**Extraneous cognitive load** is the difficulty experienced by the student when performing tasks in the quantitative structure-activity relationship laboratory activities. It is measured by obtaining the mean of items related to tasks and instruction in the cognitive load questionnaire

**Germane cognitive load** is the difficulty experienced by the student when organizing, relating and synthesizing concepts related to the biochemistry topic and the quantitative structure-activity relationship laboratory activities. It is measured by obtaining the mean of items related to organization, relation and synthesis in the cognitive load questionnaire.

**Intrinsic cognitive load** is the difficulty experienced by the student when learning a main biochemistry topic in the laboratory activity using the quantitative structure-activity relationship. It is measured by obtaining the mean of items related to topics of laboratory activity in the cognitive load questionnaire.

**Item difficulty** is operationally defined as the logit measure of relative effort in answering an item correctly in the test or instruments used in this study. It is obtained after performing dichotomous Rasch analysis or Rasch partial credit model. For Rasch partial credit model, item difficulty is obtained using racked analysis anchored on student ability.

**Logit** is operationally defined as a linear unit which is used as a measure of student ability and item difficulty in a Rasch model.

**Mereology-based Instruction** is operationally defined as type of Biochemistry instruction involving false reductionist *part-whole* relationship embedded in argumentation and quantitative structure relationship laboratory activities of the students' biochemistry subject.

**Prior knowledge of chemistry concepts** is operationally defined as the prior conceptual understanding of general inorganic chemistry, thermochemistry and general organic chemistry. It is measured by obtaining the ability logit in prior knowledge of chemistry concepts test after using dichotomous Rasch analysis.

**Prior Knowledge of visual representations** is operationally defined as prior conceptual understanding of conventional models of molecular representation, skeletal models, ball and stick models, and electrostatic potential map. It is measured by obtaining the ability logit in visual representations test after using dichotomous Rasch analysis.

**Quantitative structure-activity relationship (QSAR) laboratory activity** is operationally defined as a task involving investigation of relationship between molecular descriptors from ChemDes and MolView and quantitative *in vitro* assay results expressed in percentage or concentration.

**Rasch learning gain** is operationally defined as the difference between pretest and posttest student ability measured in logit after stacked analysis using Rasch partial credit model.

**Student** is operationally defined as a male or female second year BS Medical Laboratory Science college student who is currently enrolled in Biochemistry.

**Student ability** is operationally defined as the logit measure obtained from dichotomous Rasch analysis or Rasch partial credit model in the research instruments and tests. For Rasch partial credit models, student ability is obtained using stacked analysis anchored on items.

**Total cognitive load** is operationally defined as the measured person ability (logit) in the cognitive load questionnaire. It subsumes intrinsic cognitive load, extraneous cognitive load and germane cognitive load.

# CHAPTER 3

# METHODOLOGY

This chapter presents the research design, description of the population of the study, discussion of the components of chemical mereology-based instruction, details and procedures of data gathering methods and data analysis.

## Research Design

This utilized a pretest-posttest alternative treatment control group design to determine the effects of mereology-based instruction on chemical identity thinking, critical thinking and chemistry-based health literacy of students. The research design diagram is illustrated in Figure 3.1.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CI Group: | $O_1$ | $O_2$ | $O_3$ | $O_4$ | $O_5$ | $X_1$ | $O_6$ | $O_7$ | $O_8$ |
| MBI Group: | $O_9$ | $O_{10}$ | $O_{11}$ | $O_{12}$ | $O_{13}$ | $X_2$ | $O_{14}$ | $O_{15}$ | $O_{16}$ |

*Figure 3.1.* Research design diagram

CI: Conventional Instruction

MBI: Mereology-based Instruction

$O_1$ and $O_9$: Prior conceptual understanding of chemistry test

$O_2$ and $O_{10}$: Prior knowledge of visual representation test

$O_3$ and $O_{11}$: Chemical identity thinking pretest

$O_4$ and $O_{12}$: Critical thinking in chemistry pretest

$O_5$ and $O_{13}$: Chemistry-based health literacy pretest

$X_1$ = Exposure to conventional instruction (CI)

$X_2$ = Exposure to mereology-based instruction (MBI)

$O_6$ and $O_{14}$: Chemical identity thinking posttest

$O_7$ and $O_{15}$: Critical thinking in chemistry posttest

$O_8$ and $O_{16}$: Chemistry-based health literacy posttest

## Sample

A total of 608 students composed of 133 male students and 475 female students from thirteen intact classes participated in this study. The students were second year BS Medical Technology enrollees in biochemistry during the first semester of school year 2019-2020, and are qualified based on the inclusion criteria: a) male or female, b) currently enrolled in biochemistry course, c) has completed general inorganic and organic chemistry course, d) 18-20 years old, and e) willing to participate in the study. Seven intact classes were randomly assigned to mereology-based instruction group, while the six intact classes were assigned to the conventional instruction group.

During the course of the intervention, 5.10% of the participants (11 male students and 20 female students) opted to withdraw during the final term of the semester and did not answer the posttest. Hence, the final set of complete data was from 577 participants comprised of 290 students in mereology-based instruction group (17.50% males, 82.50% females), and 287 students in conventional instruction group (22.65% males, 77.35% females).

### Interventions

In both mereology-based instruction group and conventional instruction group, the lesson starts with a reading assignment regarding the incoming topic in the lecture class. After reading the assignments, the students are introduced to the topic in the lecture class. Since the lecture class is followed immediately by the laboratory class, the discussions in the lecture class are reiterated in the laboratory class. The QSAR laboratory activity is introduced for both classes. The laboratory activities are the same in all contents, except for the argumentation part.

In the conventional instruction classes, the argument is based on a structure-property or structure-function relationship concept, while in the mereology-based instruction group, the argumentation component is based on a part-whole relationship, which is presented in a syllogism format. In both classes, all students per group are required to create an argument using the prescribed Toulmin Argumentation Pattern (TAP) format. The output is evaluated using a researcher-made scoring rubric based on the components of the argument using the TAP format. Each group exchange their work in the next meeting for critique from other groups.

The literature readings are done independently and are used by the students during their presentation and critique of other group's argument. After the argumentation activities, students will submit their laboratory report with the answers to the research questions. The laboratory reports are evaluated using the Modified Hoyo Critical Thinking Evaluation Rubric for Laboratory Work Reports. The laboratory notebooks were also submitted to review the data gathered by students and the flow of their initial analysis in the laboratory. Each research question addresses a concept in the method used in the performance of laboratory activities or the health-related applications of the QSAR activities. The research questions are the same for both conventional instruction group and mereology-based instruction group. Lastly, all students are requested to evaluate the activity using the Cognitive Load Questionnaire, which is compiled by the researcher in Excel format for Rasch analysis. The next cycle begins when the teacher assigns a new assignment related to the next topic to be discussed int the lecture and laboratory classes.

The sequence of topics in the lecture and laboratory was modified based on the sequence of functional groups discussed during organic chemistry. The topics related to biomolecules started with selected lipid molecules, followed by selected saccharides, nucleic acids and proteins. The examination and quizzes were only based on the QSAR activity which do not require students to apply structure-activity relationship or part-whole relationship thinking. Quizzes and examinations were deliberated and prepared by all Biochemistry instructors who attended the training-workshop, including the researcher.

A bimonthly to monthly meeting was conducted and spearheaded by the researcher to assess the progress of each class in performing the QSAR activities and in constructing arguments using the Toulmin Argumentation Pattern using the arguments presented in the laboratory manual of conventional instruction group and mereology-based instruction group. In cases where a face-to-face meeting was not possible due to exam weeks, cancellation of classes and other school events, concerns were also addressed and answered via email.

All laboratory reagents and materials were provided and prepared by the researcher. The reagents were dispensed in plastic vials and placed in the laboratory kit. The use of equipment was also coordinated by the researcher with the Biochemistry instructors and laboratory technicians. The lecture learning material was also prepared by the researcher to ensure that there is no deliberate teaching of *part-whole* analysis. Examples of researcher-made learning materials and lab kits are presented in Figure 3.2.

The QSAR activities in the laboratory manual were evaluated by a professor from the Institute of Chemistry, UP Diliman whose area of research is computational chemistry, and a PhD Chemistry Education professor from University of Baguio. All QSAR activities were revised based on the comments and suggestions of the evaluators. The contents of the learning material were presented to the department head of the Medical Laboratory Science and to the dean of the School of Natural Sciences of Saint Louis University for approval and evaluation.

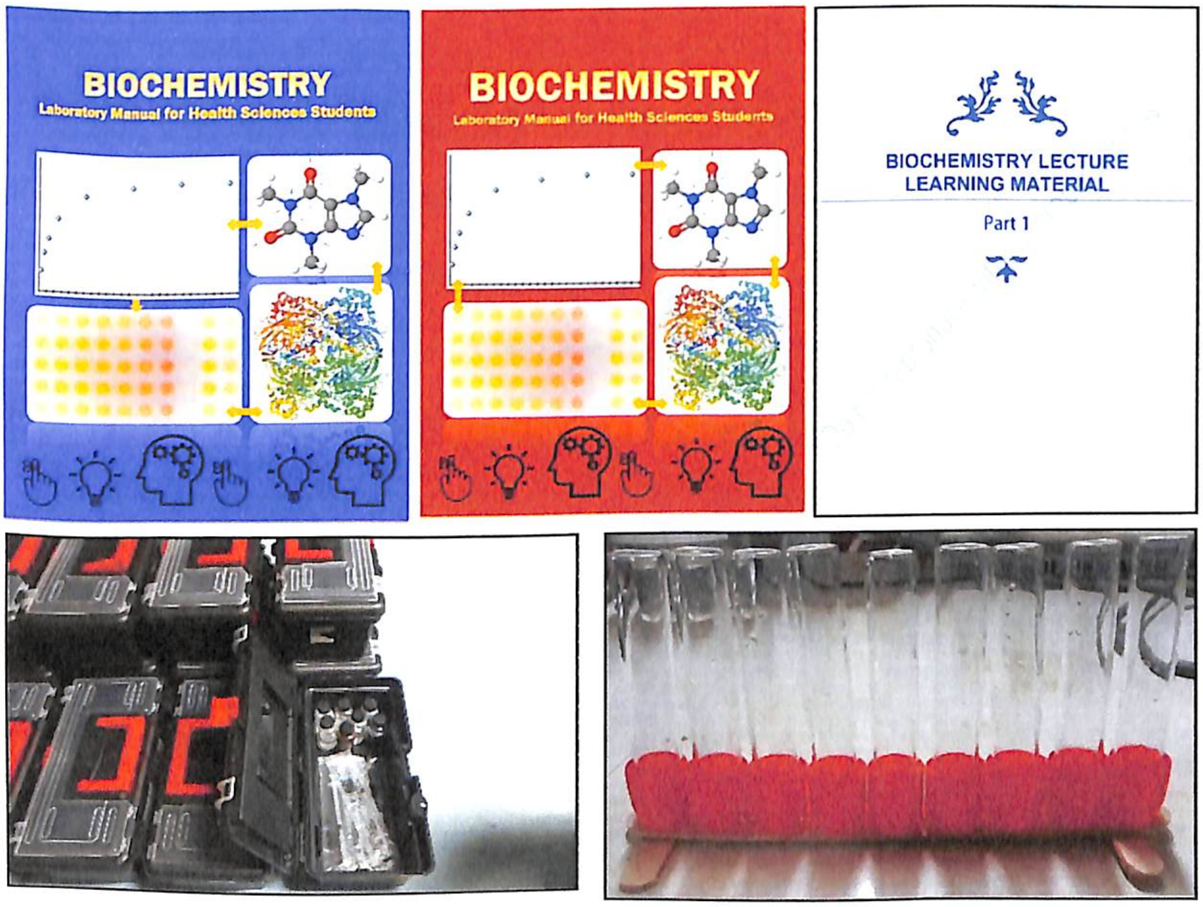


*Figure 3.2.* Sample researcher-made learning materials and laboratory kit

Journal articles which were relevant to the QSAR laboratory activities and critical thinking laboratory activities were provided by the researcher via Google classroom. Only freely accessible journal articles were selected from highly reputable publishers (Scopus or ISI-indexed journals).

For QSAR activities, all groups were requested to bring one laptop per group for *in silico* analysis during laboratory session. Students perform correlation analysis of molecular descriptors and formulated a linear regression equation, which requires deliberation from all members of the group. Only two variables were chosen. The schedule of activities, submission of outputs and quizzes were coordinated with all Biochemistry instructors. Permission to modify the laboratory activities was sought from the department head, dean and other institutional leaders prior to the implementation of the study.

During data gathering, the names of the students were coded using a group-number-class code acronym (example: MBI-01-A or CI-01-B). The record of student information, filled up consent forms and answers to research instruments were kept in a sealed cabinet for access and assurance of anonymity. Only the researcher had access to all student information and answers. When explanations were submitted to raters, only the codes of the students were indicated in the file to ensure anonymity.

## Data Gathering Instruments

There were six research instruments used in this study, comprised of two multiple-choice tests, three multitiered tests and one Likert questionnaire. The multiple-choice tests were the prior knowledge of chemistry concepts test (PKCCT) and the visual representations test (VRT). The multi-tiered tests were chemical identity thinking instrument (CITI), critical thinking test in chemistry (CTTC) and chemistry-based health literacy test (CbHLT). The details for the development and administration of each research instrument are discussed in the following paragraphs.

### Prior Knowledge of Chemistry Concepts Test

The first version of prior knowledge of chemistry concepts test (PKCCT_v01) - was originally composed of 54 items (49 multiple choice items and 5 problem-solving items) about concepts in inorganic chemistry and organic chemistry. A correct answer in each of the item is scored "1" while a wrong answer is scored "0". The test was validated by three PhD Chemistry professors, one PhD Biochemistry professor and one PhD Chemistry Education professor.

Validity was obtained using Lawshe Content Validity Index and researcher-made content validity form. The procedure and interpretation of Lawshe Content Validity Index was based on previous studies (Ayre & Scally, 2014; Gilbert & Prion, 2016). In an item level, the item content validity index (I-CVI) was computed as the number of experts evaluating an item as "essential" divided by the total number of experts. Relevancy is based on how the item relates to the construct of the instrument. The validator can rate each item as non-essential (NE), useful (U) or essential (E) based on how each item relates to the main construct or concept of the test or instrument. The item-content validity index expresses the proportion of agreement on the relevancy of each item, which is between zero and one.

The item-content validity index was supplemented by the kappa statistic. The kappa statistic is a consensus index of inter-rater agreement that adjusts for chance agreement. Kappa provides information about degree of agreement beyond chance.

To calculate modified kappa statistic, the probability of chance agreement was first calculated for each item by following formula: $PC= [N! / A! (N-A)!] * 0.5N]$. In this formula, N refers to the number of experts in a panel and A refers to the number of panelists who agree that the item is relevant (or essential). After calculating I-CVI for all instrument items, kappa is computed by entering the numerical values of probability of chance agreement (pc) and content validity index of each item (I-CVI) in following formula: $K = (I\text{-}CVI - pc) / (1-pc)$. If the kappa values are above 0.74, between 0.60 and 0.74, and between 0.40 and 0.59, the values are classified as excellent, good, and fair, respectively. Content validity rating was performed simply by obtaining the average rating or all validators and interpreted based on the range for average rating.

After the validation of the test, the item-content validity index was determined peritem to determine which items to be retained or eliminated (sample shown in Appendix A). Content validation rating was also determined (sample shown in Appendix B). The initial difficulty of items was hypothesized based on the task involved in each item.

As advised, the sequence of the items was modified, and some items were reconstructed based on the suggestion of the validators. The second version of PKCCT (PKCCT_v02), which is the validated version, was composed of 50 multiple-choice items and was submitted for ethics review last March 6, 2019 to allow pilot testing to various universities. The research protocol was approved last March 21, 2019 with the following revisions: (a) research instruments were brought to the different universities during pilot testing, (b) informed consent forms were obtained prior to pilot testing, (c) codes of each respondent were shortened, and (d) dates for pilot tests were changed because some universities refused to participate. The research protocol was assigned with approval certificate number SLU-REC 2019-045.

Letters of communication were sent to three institutions for the coordination of schedule for pilot testing (sample shown in Appendix C). After approval, a total of 374 students composed of 46 second year BS Chemistry students from one institution in Laguna, 114 first year medical technology students in one institution in Manila, and 214 first year BS Pharmacy students in one university in Baguio City were recruited to answer PKCCT_v02.

The values obtained from the data were compared to the specific range of values of person and item separation and reliability, item fit statistics such as MNSQ and ZTSD, point measure correlation, an unidimensionality using the eigenvalue of the first contrast by utilizing dichotomous Rasch analysis in Winsteps version 4.4.5. In the dichotomous Rasch model, the probability of a person's response to an item is a function of the difference between the item's location in the linear logit scale and the person's location in the same logit scale, this particular Rasch model is commonly used in a test which has either correct or wrong answer. Rasch parameter such as person and item reliability index, person and item separation index, item difficulty, item polarity, and unidimensionality were evaluated.

Dichotomous Rasch analysis is commonly used in multiple choice tests (Boone & Scantlebury, 2006) and is based on the mathematical model:

$$ln\left(\frac{P_{ni}}{1-P_{ni}}\right) = B_n - D_i$$

Where $B_n$ is the ability of the person $n$, $D_i$ is the difficulty of item $i$ and the probability ($P$) of a person answering an item is related to the person ability and item difficulty. Both person ability and item difficulty are converted into logits, and may be presented in the same linear scale using what is called a Wright Map.

In contrast, the partial credit Rasch model indicates that each item has its own rating scale structure. It is more appropriate for tests that have responses which can be given partial credit towards a correct response. The amount of partial correctness varies across items. The partial credit model is a version of the rating scale model and is described mathematically as:

$$ln\left(\frac{P_{nij}}{P_{ni(j-1)}}\right) = B_n - D_i - F_{ij}$$

Where:

$F_{ij}$ = threshold between categories $j$ and $j-1$ on item $i$.

In contrast to the rating scale model, the items of the same raw score can have different values of Rasch difficulties if the pattern of category usage on those items is different (Bond & Fox, 2007; Bond et al., 2020; Planinic et al., 2019).

Furthermore, other properties of the test such as item separation, item reliability, person separation, person reliability, unidimensionality, fit statistics (infit and outfit MNSQ and ZTSD) and point measure correlation are provided to determine if the items fit the Rasch model. If the test fits the Rasch model and satisfies unidimensionality and local independence, then the measurements from the Rasch analysis are trustworthy (Wei et al., 2012). The parameters of Rasch analysis and their interpretation are shown in Appendix D.

The internal consistency of the test (KR-20) was computed using the software SPSS 27.0. Differential item functioning (DIF) between male and female students were also determined to remove gender bias using WINSTEPS 4.4.5. Based on DIF analysis, two items exhibited gender bias, and were subsequently removed.

After the evaluation of the psychometric properties PKCCT_v02, a total of 45 items were included in the pilot test and subsequently used

to the target participants.The final version of the test is composed of 20 items in general inorganic chemistry topics, 4 items in thermochemistry and 21 items in general organic chemistry topics. The summary of Rasch analysis is presented in Table 3.1, indicating that PKCCT_v02 fits the Rasch model, and is appropriate for the target participants.

The final version of this test is called prior knowledge of chemistry concepts test (PKCCT) and is used to obtain the student ability measures (logit) and item difficulty measures (logit). Student ability logits were used in subsequent statistical analysis. The details of each item in PKCCT are summarized in Appendix E.

Table 3.1.

*Psychometric properties of prior knowledge of chemistry concepts test*

| Parameter | Results | Interpretation |
|---|---|---|
| Person separation | 1.47 | Test may discriminate 1 or 2 levels only (Boone et al., 2014). |
| Person reliability | 0.68 | Test may discriminate 1 or 2 levels only. |
| Item separation | 5.73 | There are 6 levels of difficulty. |
| Item reliability | 0.97 | Item difficulties have high reproducibility. |
| Fit statistics | | |
| Infit MNSQ | 0.87 to 1.12 | The items fit the dichotomous Rasch model. |
| Outfit MNSQ | 0.84 to 1.14 | ZTSD measures can be ignored if MNSQ |
| Infit ZTSD | -4.41 to 3.51 | values are within the acceptable range |
| Outfit ZTSD | -4.42 to 3.27 | (Boone et al., 2014) |
| Point measure correlation range | 0.06 to 0.49 | All items contribute to the measurement of the construct. |
| Unidimensionality | | |
| Eigenvalue of 1st contrast | 1.71 | The test is unidimensional. |
| PCA disattenuated correlation range | 0.55 to 0.83 | |
| KR-20* | 0.70 | The test has adequate internal consistency. |
| Person Measure | -1.63 to 1.58 | Items are within the person measure. |
| Item Measure | -1.63 to 2.12 | |
| Person and item mean difference | 0.49 | **Mean item difficulty is higher, but is appropriate for target participants. |

*analyzed using SPSS 27.0

**Mean item difficulty is 0.49 logit above the mean person ability

## Visual Representations Test

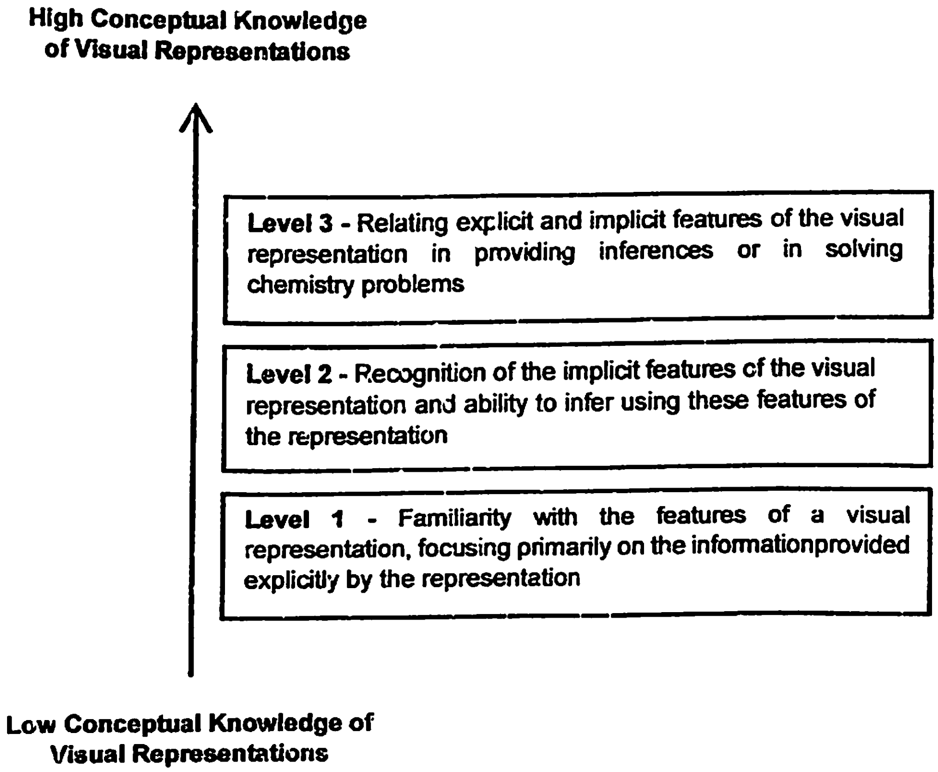
The first version of the Visual Representations Test (VRT_v01) was composed of 26 multiple-choice test questions. The test items require the interpretation and analysis of skeletal structures, ball and stick models, van der Waals sphere models, and electrostatic potential maps (EPM). A correct answer in each of the item is scored "1" while a wrong answer is scored "0".

The first version of the test was evaluated by four PhD Chemistry professors, two PhD Chemistry Education professor and one PhD Biochemistry professor, to determine whether the test items are measuring prior understanding of visual representations. After validation of the test, the item-content validity index was determined per item to determine which items to be retained or eliminated (Appendix F). Content validity rating was also determined (Appendix G) to improve the test. The procedure of obtaining item content validity and content validity rating was similar to the method used in prior knowledge of chemistry concepts test.

One item was eliminated based on the results of item content validity index. Items which focus on the electrostatic potential map (EPM) models were reconstructed based on the suggestions of the validators. Three additional items were also included in the second version of the test. Furthermore, the choices in each item were revised to ensure that there is only one correct answer per item. The second version of Visual Representations Test (VRT_v02) was composed of 25 items.

The protocol for conducting the pilot test for Visual Representations Test was submitted for ethics review on March 6, 2019, approved on April 10, 2019 and was assigned an ethics approval certificate SLU-REC 2019-044. The test is constructed according to the learning progression (Figure 3.4) developed by the researcher, basing it on previous studies (Mnguni et al., 2016; Rau, 2016; Schönborn & Anderson, 2010).

The proposed learning progression for visual representations test was developed by determining the characteristics of students in the lowest level and highest level in the proposed learning progression (Figure 3.3.). Then, a logical sequence of skills that a student or learner may exhibit when transitioning towards the highest level is proposed within the learning progression. The characteristics of students with low conceptual understanding of visual representations was based on the level of difficulty of visualization skills proposed by Mnguni et al., 2016, which includes describing, classifying, ordering, and explaining what visual representations are. Furthermore, learners with low visual literacy often focus on surface characteristics of visual representations, such as shape, color or size.


**High Conceptual Knowledge of Visual Representations**

**Level 3** - Relating explicit and implicit features of the visual representation in providing inferences or in solving chemistry problems

**Level 2** - Recognition of the implicit features of the visual representation and ability to infer using these features of the representation

**Level 1** - Familiarity with the features of a visual representation, focusing primarily on the informationprovided explicitly by the representation

**Low Conceptual Knowledge of Visual Representations**

*Figure 3.3.* Hypothesized progression of conceptual knowledge of visual representations

When a learner understands the explicit or surface characteristics of a visual representation, they can relate the features of one visual representation to another visual representation (Rau, 2016). A student who claims that a ball and stick model and Lewis's dot structure of a water molecule are depicting the same molecule characterizes this level of understanding. Student can claim that the ball and stick model provide other features such as molecular geometry, which complement the information in the Lewis dot diagram. A student may also infer that the molecule is polar based on electronegativity differences in the atomic composition. Polarity is classified as an implicit feature in this case.

Lastly, being able to use explicit and implicit features in solving a problem constitutes the highest level as students may shift from one representation to another or use deduction and develop inferences based on the combination of representations. This resonates with the "externalization" level depicted by Mnguni et al. (2016), which characterizes a learner with high level of visual literacy to infer, complete, propose, develop, formulate, and use a visual representation. In this study, the proposed learning progression was iteratively modified based on the Rasch analysis result during the pilot test, since the resulting realistic range of skills is only depictive of health science students who did not have prior knowledge of visual representations compared to students who already completed advanced chemistry subjects such as analytical chemistry and biochemistry.

After securing ethics approval, letters of communication were sent to the dean and coordinators to selected institutions for approval and coordination of pilot testing of the second version of the test (VRT_v02). A total of 404 students who have finished general inorganic chemistry and organic chemistry participated during the pilot test. The respondents included 91 first year BS Biology students from a university in Baguio City, 92 first year BS Pharmacy students from a university in Baguio City, 24 first year BS Medical Technology students from a university in Pampanga, and 197 first year BS Medical Technology students from a university in Manila.

The results were evaluated using dichotomous Rasch analysis using WINSTEPS version 4.4.5. Rasch parameter such as person and item reliability index, person and item separation index, item difficulty, item polarity, and unidimensionality were evaluated. The internal consistency of the test was also computed by the software SPSS 27.0. Differential item functioning (DIF) between male and female students were also determined to remove gender bias. Based on DIF two items exhibited gender bias.

After the evaluation of the psychometric properties VRT_v02, a total of 23 items were included in the last pilot visual representations test and subsequently used to the target participants. The final version of the test was composed of 5 items related to conventional visual representations (particle models, Newman projection), 12 items related to skeletal structures, 3 items in ball and stick model, and 3 items in EPM models. The details of visual representations test items are in Appendix H.

The summary of dichotomous Rasch analysis is presented in Table 3.3, indicating that VRT_v03 fits the Rasch model, and is appropriate for the target participants. The final version of this test was called visual representations test (VRT), and was used to obtain the student ability measures (logit) and item difficulty measures (logit). Student ability logits were used in subsequent statistical analysis.

**Table 3.2.**

*Psychometric properties of visual representations test*

| Parameter | Results | Interpretation |
|---|---|---|
| Person separation | 1.34 | Test may discriminate 1 or 2 levels only (Boone et al., 2014) |
| Person reliability | 0.64 | Test may discriminate 1 or 2 levels only. |
| Item separation | 5.19 | There are 5 levels of difficulty. |
| Item reliability | 0.96 | Item difficulties have high reproducibility. |
| Fit statistics | | |
| Infit MNSQ | 0.87 to 1.23 | The items fit the dichotomous Rasch model. ZTSD measures can be ignored if MNSQ values are within the acceptable range (Boone et al., 2014) |
| Outfit MNSQ | 0.85 to 1.24 | |
| Infit ZTSD | -2.20 to 2.28 | |
| Outfit ZTSD | -1.64 to 2.08 | |
| Point measure correlation range | 0.03 to 0.51 | All items contribute to the measurement of the construct. |
| Unidimensionality | | |
| Eigenvalue of 1st contrast | 1.90 | The test is unidimensional. |
| PCA disattenuated correlation range | 0.95 to 1.00 | |
| KR-20* | 0.74 | The test has adequate internal consistency. |
| Person Measure | -2.09 to 1.18 | Items are within the person measure. |
| Item Measure | -2.26 to 2.23 | |
| Person and item mean difference | 0.31 | **Mean item difficulty is higher than mean person ability logit. |

*Analyzed using SPSS 27.0

**Mean item difficulty is 0.31 logit above the mean person ability logit.

## Chemical Identity Thinking Instrument

The first version of Chemical Identity Thinking Instrument (CITI_v01) was developed based on the study conducted by Ngai (2017). The work of Ngai (2017) focused on the rigorous development of an instrument involving qualitative data to diagnose chemical identity thinking, leading to the development of a learning progression corresponding to *objectivization*, *principlism*, *compositionism*, and *interactionism*.

Based on reasoning patterns, *objectivization* (first level) utilizes functional usage, historicality, and surface similarity. The second level, *principlism*, relies on historicality, surface similarity, substantialization, and additivity. *Compositionism,* the third level, relies on *additivity* and *elementalism*. The last level, *interactionism*, relies on structuralism and emergence. These levels were utilized to characterize the reasoning patterns of students in the Chemical Identity Thinking Instrument in this study. The instrument was composed of 24 items involving substances and mixtures. The items were included because they can elicit *objectivization*, *principlism*, *compositionism* and *interactionism* explanations from students.

The first part was composed of 10 items which require students to determine whether the samples were similar or different. Students were required to provide explanations afterwards. The second part of the instrument was composed of 14 items which required students to explain their answers to differentiate materials, substances or molecules.

The protocol for conducting the pilot test for Chemical Identity Thinking Instrument was sent to two PhD Chemistry Education professors, one PhD Chemistry professor and one PhD Biochemistry professor for content validation. Four items were deleted after content validation, and the resulting second version was assigned CITI_v02. The details of the item-content validity index and content validation rating are presented in Appendix I and Appendix J. The procedure of obtaining item content validity and content validity rating was similar to the method used in prior knowledge of chemistry concepts test.

The revised instrument was submitted for ethics review prior to pilot testing last February 18, 2019 and was approved last March 25, 2019 and assigned with ethics approval certificate SLU-REC 2019-021. The test was constructed based on the learning progression (Figure 3.4) developed by the researcher based on the study of Ngai (2017). Since the learning progression only encompasses the construct for students who finished biochemistry and those who had no prior exposure, there were only 5 levels proposed and tested using Rasch partial credit model. The levels guided the evaluation of the answers and characterize the types of chemical identity thinking to the target participants only prof. But if the target participants are more diverse, the levels can be modified. Since this study only dealt with health science students, this served as the guide in determining changes from pretest to posttest, after the target participants were exposed to the teaching intervention.

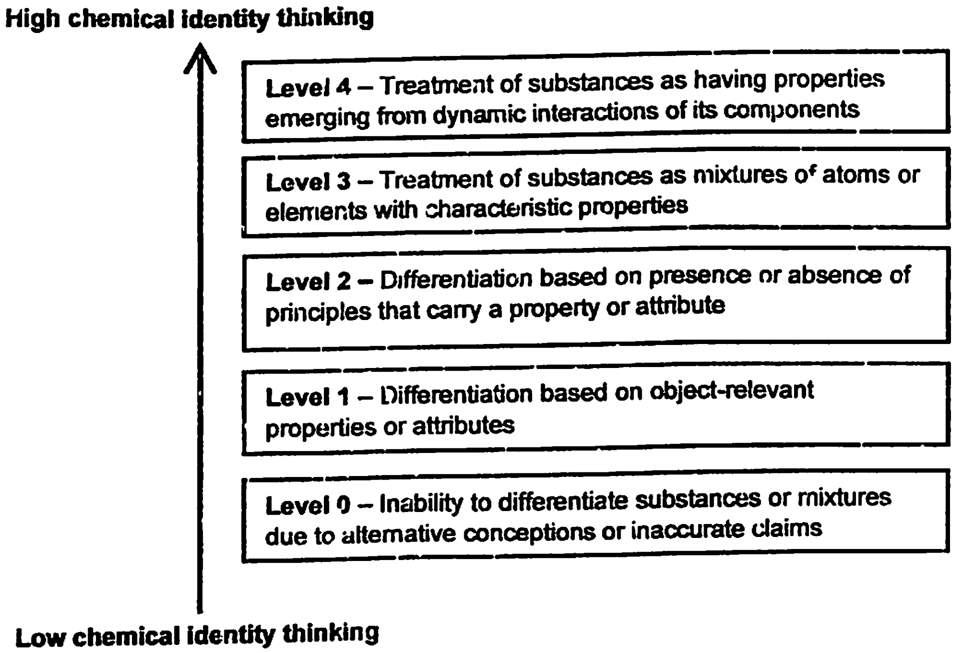


*Figure 3.4.* Hypothesized progression of chemical identity thinking

Letters of communication were sent to three institutions for the coordination of schedule for pilot testing. After approval, a total of 362 students composed of 101 third year BS Medical Technology students from one institution in Manila, Metro Manila, 24 second year medical technology students from one university in

Pampanga, 113 second year BS Medical Technology students from one university in Quezon City, Metro Manila, 91 second year BS Biology students from one university in Baguio City, and 33 second year BS Medical Technology students from one university in Pampanga were recruited to answer CITI_v02.

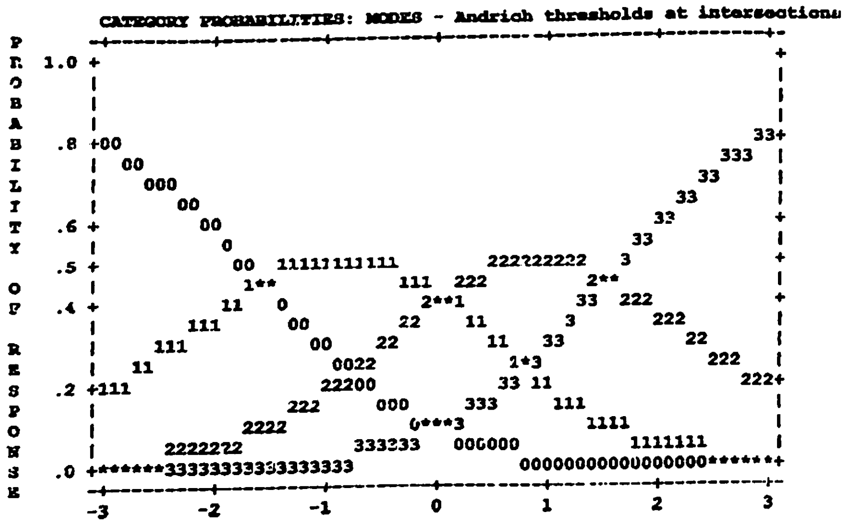
All answers were encoded and transcribed in Microsoft Excel, then sent to two raters. The first rater was a BS Chemistry graduate, while the second rater was a graduate of MS Chemistry. All answers were rated independently using the rubric in Table 3.3. Interrater correlation was determined to be 0.915 for 160 items. Items which were unclear were discussed via email. The raters for pilot test were also the rater during pretest and posttest.

**Table 3.3.**

*Rubric for the evaluation of answers in chemical identity thinking instrument*

| Level | Accuracy of explanation | Type of Explanation | Score |
|---|---|---|---|
| 3 | Correct Answer | Compositionism or Interactionism | 3 |
| 2 | Correct Answer | Principlism | 2 |
| 1 | Correct Answer | Objectivization | 1 |
| 0 | Incorrect Answer | •<br>Alternative conception<br>Unrelated<br>*"I don't know"* | 0 |

The data obtained from pilot test was analyzed by assigning a color code for each explanation, and a number code for the accuracy. The combination of accuracy and type of explanations were coded using the scores 0, 1, 2 and 3. Rasch partial credit model was conducted to determine the psychometric properties of the instrument. The results are presented in Table 3.4. Iterative analysis using five levels was analyzed, but level 3 and level 4 were combined based on their conflated item category thresholds as explained in the following statements. When evaluating the category thresholds, the boundaries of each category should be distinct. When the boundaries of two categories are not distinct, the two categories need to be collapsed or combined into one category. In the analysis of the data using Rasch partial credit model, the hypothesized Level 3 and Level 4 in Figure 3.5. exhibited overlapping, or indistinct category thresholds. Hence, Level 3 and Level 4 were collapsed into Level 3, which is characterized by students who treats substances as mixtures of atoms or elements with distinct properties, and treating substances as having properties emerging from dynamic interactions of its components. The final Andrich thresholds indicate that the four final categories have distinct item thresholds, as shown in Figure 3.5. The details of items in chemical identity thinking instrument are presented in Appendix K.



```
         CATEGORY PROBABILITIES: MODES - Andrich thresholds at intersections
P       -+---------+---------+---------+---------+---------+---------+-
R   1.0 +                                                            +
O       |                                                            |
B       |                                                            |
A       |                                                            |
B    .8 +00                                                        33+
I       |  00                                                   333  |
L       |    000                                              33     |
I       |       00                                          33       |
T    .6 +         00                                      33         +
Y       |          0                                    33           |
     .5 +           00  11111111111        222222222   3             +
O       |            1**           111  222         2**              |
F    .4 +          11   0            2**1          33  222           +
        |       111      00        22    11       3       222        |
R       |    111           00    22        11   33          22       |
E       |   11               0022            1*3               222   |
S    .2 +111                22200           33 11                 222+
P       |                222     000     333     111                 |
O       |            2222           0***3           1111             |
N       |     2222222          333333   000000          1111111      |
S    .0 +******33333333333333333              00000000000000000******+
E       -+---------+---------+---------+---------+---------+---------+-
        -3        -2        -1         0         1         2         3
```

*Figure 3.5.* Rasch Andrich threshold of categories in chemical identity thinking instrument

Based on the results of Rasch partial credit model, the learning progression was modified to combine Level 3 and Level 4. Hence, the learning progression for chemical identity thinking was modified (Figure 3.6) and subsequently used during pretest and posttest. The scoring rubric to evaluate CITI_v01 is shown in Table 3.4. The level corresponding to the hypothesized learning progression was scored accordingly to all items in the instrument.

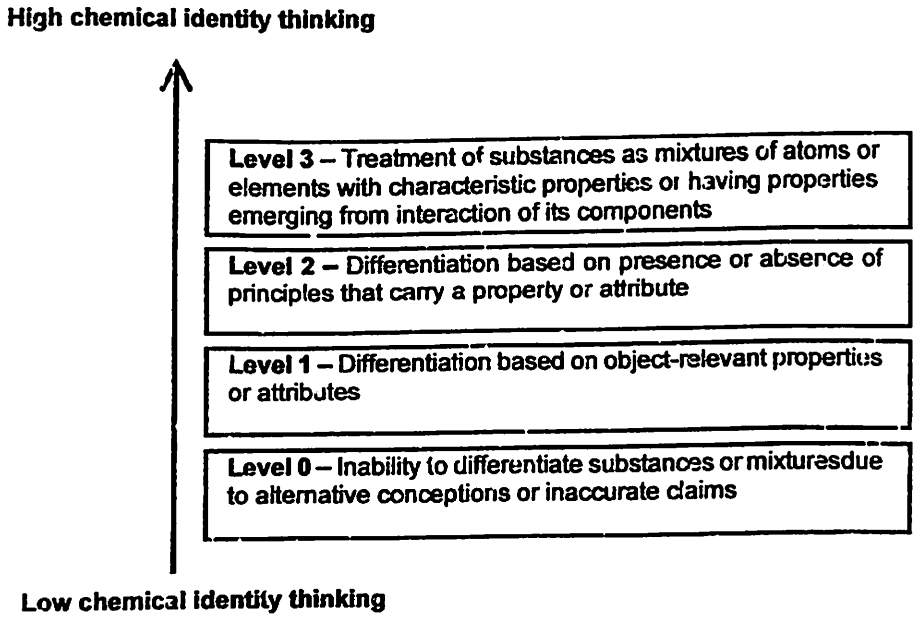


*Figure 3.6.* Revised progression of chemical identity thinking

After performing Rasch partial credit model, the results are summarized in Table 3.4., indicating that the instrument fits the Rasch model based on the study of Ngai (2017).

**Table 3.4.**

*Psychometric properties of chemical identity thinking instrument*

| Parameter | Results | Interpretation |
|---|---|---|
| Person separation | 1.81 | Person separation is acceptable (Boone et al., 2014) |
| Person reliability | 0.77 | Person measures can discriminate 1 or 2 levels. |
| Item separation | 7.07 | There are 7 levels of difficulty. |
| Item reliability | 0.98 | Item difficulties have high reproducibility. |
| Fit statistics | | |
| Infit MNSQ | 0.89 to 1.09 | The items fit the dichotomous Rasch model. ZTSD measures can be ignored if MNSQ values are within the acceptable range (Boone et al., 2014) |
| Outfit MNSQ | 0.88 to 1.03 | |
| Infit ZTSD | -1.64 to 1.33 | |
| Outfit ZTSD | -1.82 to 1.09 | |
| Point measure correlation range | 0.39 to 0.49 | All items contribute to the measurement of the construct. |
| Unidimensionality | | |
| Eigenvalue of 1$^{st}$ contrast | 1.51 | The test is unidimensional. |
| PCA disattenuated correlation range | 0.57 to 0.86 | |
| Cronbach alpha* | 0.77 | The test has adequate internal consistency. |
| Person Measure | -2.89 to 1.18 | Items are within the person measure. |
| Item Measure | -1.08 to 1.18 | |
| Person and item mean difference | 0.69 | **Mean item difficulty is higher than mean person ability logit |

*Analyzed using SPSS 27.0

**Mean item difficulty is 0.69 logit above the mean person ability logit

## Critical Thinking Test in Chemistry

The first version of critical thinking test is composed of 32 items which involve concepts in general inorganic and organic chemistry. In each situation, students are required to evaluate whether the final statement is *valid*, *possible*, or *invalid*. The concepts related to the critical thinking test were based on the topics in the study of Al-Balushi et al. (2012), Fernandez (2012), Fernandez (2015) and Tümay (2016).

The instrument was evaluated by four PhD Chemistry professors. The results of the item content validity indices and content validation rating are shown in Appendix L and Appendix M, respectively. The procedure of obtaining item content validity and content validity rating were similar to the method used for the priorknowledge of chemistry concepts test.

Based on the item content validity indices, four items were discarded, reducing the number of items into 28. After determining the duration for answering the items, it was decided that the items be trimmed down to 20 to reduce test fatigue. The choices were also changed into valid and invalid, based on the suggestion of the evaluators. Finally, each question was revised to improve clarity. A learning progression was hypothesized to guide the scoring of responses of students in the test (Figure 3.7). The levels in the learning progression are based on the ability to use mechanistic reasoning, which is characterized by a correct cause-effect thinking using chemistry concepts. For example, a student with mechanistic thinking may reason out that boiling of water involves breaking of hydrogen bonds from water molecules as influenced by the introduction of heat.

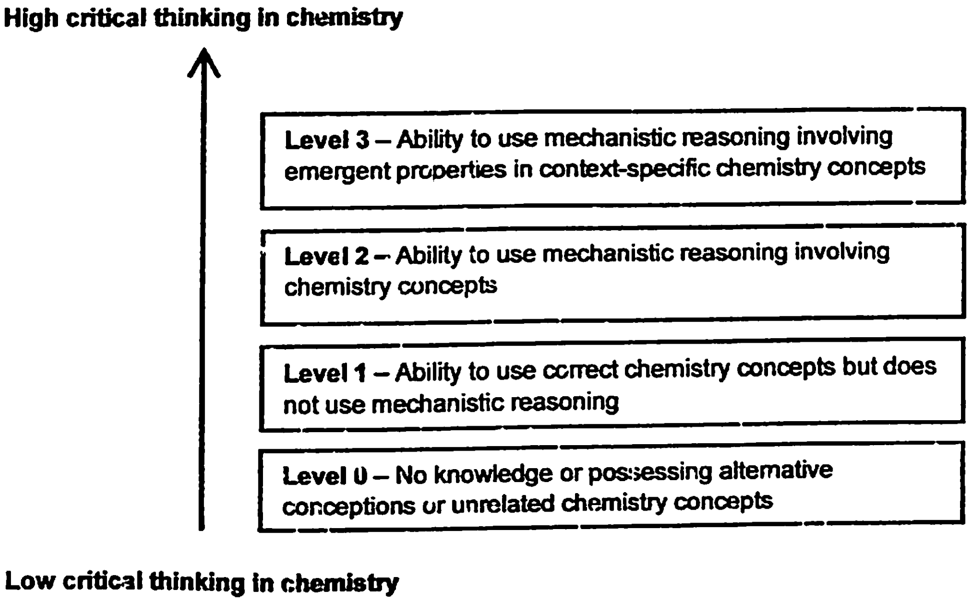


*Figure 3.7.* Hypothesized progression of critical thinking in chemistry

Prior to pilot testing of the second version of the test, a research protocol was submitted for ethics review on February 18, 2019, approved on April 10, 2019 with the ethics approval certificate SLU-REC 2019-022. The second version of the critical thinking test in chemistry (CTTC_v02) was used for pilot testing to various institutions. After ethics approval, letters of communication were sent to the deans and coordinators of several institutions for coordination of activities for pilot testing of instruments.

A total of 392 respondents comprised of 70 first year BS Medical Technology students in one university in Baguio City, 46 first year BS Chemistry students in a university in Laguna, 110 first year BS Medical Technology students from one university in Davao City, 100 first year BS Medical Technology students from Manila, and 66 first year BS Pharmacy students from a university in Baguio City.

All answers were encoded and transcribed in Microsoft Excel, then sent to two raters. The two raters were BS Chemistry graduates. All answers were rated independently using the rubric in Table 3.5, which was based on the hypothesized learning progression in critical thinking in chemistry (Figure 3.8). Interrater correlation was determined to be 0.932 for 160 items. Items which were unclear were discussed by the author with the raters via email. The raters for the pilot test were also the raters during pretest and posttest.

**Table 3.5.**

*Rubric for evaluation of answers in critical thinking in chemistry*

| Level | Accuracy of Claim | Accuracy of Explanation | Type of Explanation | Score |
|---|---|---|---|---|
| 3 | Correct | Correct | Chemistry concepts involving mechanistic reasoning and emergent properties | 3 |
| 2 | Correct | Correct | Chemistry concepts with mechanistic reasoning; disapproving chemistry explanations with mechanistic reasoning | 2 |
| 1 | Correct | Correct | Chemistry concepts but no mechanistic reasoning | 1 |
|  | Incorrect | Correct | Chemistry concepts but no mechanistic reasoning |  |
| 0 | Incorrect | Incorrect | Non-chemistry concepts or unrelated chemistry concepts; no explanation | 0 |

All answers to "accuracy of claim" were encoded as 0 for incorrect answers, and "1" for correct answers. All answers to "accuracy of explanation" were coded using colors. The final codes were determined then subjected to Rasch partial credit model using WINSTEPS 4.4.5. Furthermore, Cronbach alpha was computed using SPSS 27.0. The results of Rasch partial credit model are shown in Table 3.6.

It is indicated that the items fit the Rasch model. Upon DIF analysis, it was noted that two items were gender-biased, hence, the final items in the instrument were reduced to 18, corresponding to 5 general organic chemistry topics, five general inorganic chemistry concepts, and 8 items related to laboratory concepts.

Lastly, the threshold of categories in Figure 3.8 indicates that the four categories can be discriminated adequately. The details of items in critical thinking test in chemistry is presented in Appendix N.

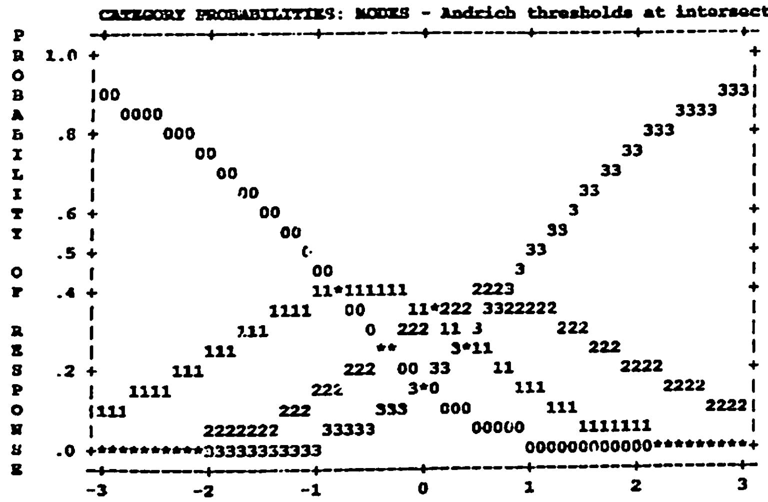
**Table 3.6.**

*Psychometric properties of critical thinking test in chemistry*

| Parameter | Results | Interpretation |
|---|---|---|
| Person separation | 2.13 | Person separation is good (Boone et al., 2014) |
| Person reliability | 0.82 | Person measures can discriminate 2 or 3 levels. |
| Item separation | 7.29 | There are 7 levels of difficulty. |
| Item reliability | 0.98 | Item difficulties have high reproducibility. |
| Fit statistics | | |
| Infit MNSQ | 0.91 to 1.08 | The items fit the dichotomous Rasch model. |
| Outfit MNSQ | 0.88 to 1.12 | ZTSD measures can be ignored if MNSQ values are within the acceptable range (Boone et al, 2014) |
| Infit ZTSD | -1.14 to 1.10 | |
| Outfit ZTSD | -1.41 to 1.55 | |
| Point measure correlation range | 0.18 to 0.63 | All items contribute to the measurement of the construct. |
| Unidimensionality | | |
| Eigenvalue of 1st contrast | 1.45 | The test is unidimensional. |
| PCA disattenuated correlation range | 0.91 to 1.00 | |
| Cronbach alpha* | 0.84 | The test has adequate internal consistency. |
| Person Measure | -3.21 to 1.72 | Items are within the person measure. |
| Item Measure | -1.00 to 0.67 | |
| Person and item mean difference | 0.70 | **Mean item difficulty is higher than the mean person ability logit |

*Analyzed using SPSS 27.0

**Mean item difficulty is 0.70 logit above the mean person ability



```
        CATEGORY PROBABILITIES: MODES - Andrich thresholds at intersections
P      -+---------+---------+---------+---------+---------+---------+-
R  1.0 +                                                             +
O      |                                                             |
B      |00                                                        333|
A      |  0000                                                3333   |
B   .8 +      000                                         333        +
I      |         00                                     33           |
L      |           00                                 33             |
I      |             00                             33               |
T   .6 +               00                            3               +
Y      |                 00                       33                 |
    .5 +                   00                   33                   +
O      |                    00                 3                     |
F   .4 +                    11*111111      2223                      +
       |                1111   00    11*222 3322222                  |
R      |             111         0  222 11 3       222               |
E      |          111             **     3*11         222            |
S   .2 +       111             222  00 33    11          2222        +
P      |   1111             222      3*0       111           2222    |
O      |111              222      333   000       111            2222|
N      |          2222222    33333         00000     1111111         |
S   .0 +**********3333333333                    000000000000*********+
E      -+---------+---------+---------+---------+---------+---------+-
       -3        -2        -1         0         1         2         3
```

*Figure 3.8.* Rasch Andrich threshold of categories in critical thinking test in chemistry

## Chemistry-based Health Literacy Test

The first version of the Chemistry-based Health Literacy Test (CbHLT_v01) was composed of 24 multiple choice items which require explanation of their answers. Basically, students are tasked to select a correct answer and provide explanations related to correct chemistry contexts. The topics were related to nutrition, pharmacology, diagnosis and natural products based on selected leading causes of mortality and morbidity in the Philippines such as diseases of the cardiovascular system, diabetes mellitus, respiratory diseases, malignant neoplasms (cancer) and communicable diseases (bacterial infections).

This study hypothesized a learning progression on chemical reasoning which is contextualized to health decisions (Figure 3.9).

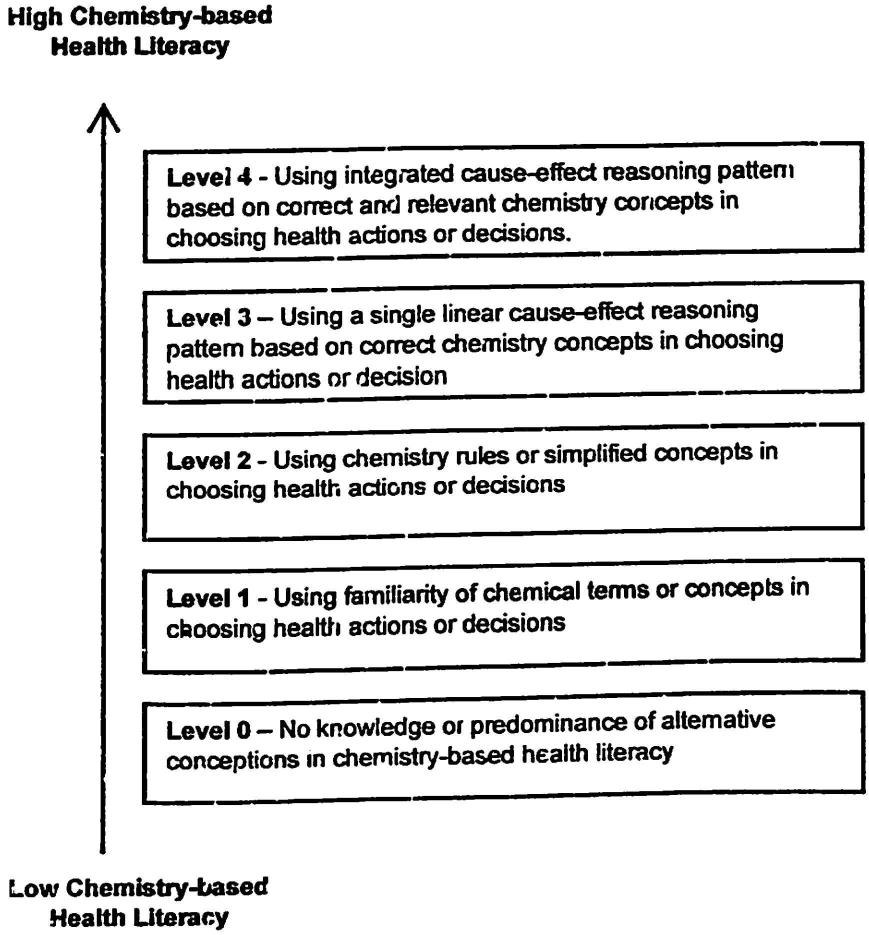


*Figure 3.9.* Hypothesized progression of chemistry-based health literacy

The levels of chemistry-based health literacy are based on the combination of four components related to the application of chemistry concepts to situations involving health. These aspects are described by each level in Table 3.7.

## Table 3.7.

*Basis for the progression of chemistry-based health literacy*

| Criteria | Level | Description |
|---|---|---|
| Linking of chemistry concepts and health decision | 4 | Linking of chemical concepts as basis to the health decision is based on multiple contexts on how chemistry concepts are linked to health concepts in the situation. |
| | 3 | Linking of chemical concepts as basis for health decision is based on linear, one-dimensional context on how chemistry concepts are linked to health concepts in the situation. |
| | 2 | Linking of chemical concepts as basis for health decision is based on similarity of concepts in chemistry and the chemistry-based concepts in the situation. |
| | 1 | Linking of chemical concepts to health decision is based on definition of chemical terms or description of chemistry concepts. |
| Appraisal of chemical information | 4 | Appraisal of chemistry information involves the recognition of limitations and strengths of chemical data which are relevant to the context of the health situation. |
| | 3 | Appraisal of chemistry information involves recognition of limitations and strengths of chemical data without involving the context of the situation. |
| | 2 | Appraisal of chemistry information is based on the similarity of the chemical concept which was previously learned to the health situation but without involving the context of the situation. |
| | 1 | Appraisal of chemistry information is based on familiarity of definitions of chemical terms or concepts only. |
| Inference from chemical data | 4 | Inferences from chemical data are based on the nature of the chemical information and its suitability to be applied in the situation. |
| | 3 | Inferences from chemical data are based on the nature of chemical information and its similarity to the chemical concepts related to the situation. |
| | 2 | Inferences are based on simplified rules in chemistry. |
| | 1 | Inferences are limited and are based on definition of chemical terms and concepts only. |
| Application of latent and explicit chemistry concept in the situation | 4 | Application of related macroscopic and abstract chemistry concepts (sub-microscopic or symbolic) which are not stated in the situation in addition to explicitly stated chemistry concepts. |
| | 3 | Application of macroscopic concept or chemistry rules which are stated in the situation. |
| | 2 | Application of simplified chemistry rules or concepts which are not stated in the situation. |
| | 1 | Utilization of chemistry concepts and definitions without applying them to the health situation. |

The first version of chemistry-based health literacy test was evaluated by four PhD Chemistry professors and one PhD Chemistry Education professor. Based on item content validity indices, eight items were acceptable while 12 items needed revision. Based on the comments of the evaluators, four items were deleted, reducing the number of items to 20. Furthermore, the questions and options were made shorter to increase clarity. The second version of Chemistry-based Health Literacy Test (CbLHTv02) was prepared for pilot testing. The results of the item content validity indices and content validation rating are shown in Appendix O and Appendix P, respectively. The procedure of obtaining item content validity and content validity rating was similar to the method used in prior knowledge of chemistry concepts test.

The research protocol for pilot testing of CbHLTv02 was submitted for ethics review last February 18, 2019. The protocol was approved last March 21, 2019 and was assigned with Protocol Number SLU-REC 2019-023. After ethics approval, letters of communication were sent to different institutions offering BS Medical Laboratory Science or BS Medical Technology to coordinate the schedule for pilot testing.

A total of 517 respondents answered CbHLT_v02. This population consists of 97 first year BS Medical Laboratory Science students from a university in Baguio City, 52 third year BS Medical Technology students from a university in Manila, 92 first year BS Medical Technology students from another institution in Manila, 107 first year BS Medical Laboratory Science students from a university in Quezon City, Metro Manila, 65 first year BS Medical Technology students from a university in Pampanga, and 104 first year BS Medical Technology students in one institution in Davao City.

**Table 3.8**

*Initial rubric for the evaluation of chemistry-based health literacy test*

| Level | Accuracy of Claim | Accuracy of Explanation | Type of Explanation | Score |
|---|---|---|---|---|
| 4 | Correct | Correct | Multiple chemistry and health concepts involving mechanistic reasoning related to the health context | 4 |
| 3 | Correct | Correct | Single chemistry concepts linked with a health concept with mechanistic reasoning or disapproving chemistry explanations with mechanistic reasoning related to the health context | 3 |
| 2 | Correct | Correct | Chemistry concepts but no mechanistic reasoning related to health context | 2 |
| 1 | Correct | Correct | Non-chemistry concepts or unrelated chemistry concepts; no explanation | 1 |
| 0 | Incorrect | Correct or Incorrect | Non-chemistry concepts or unrelated chemistry concepts; no explanation | 0 |

All answers were encoded and transcribed in Microsoft Excel, then sent to two raters. All answers were rated independently using an initial rubric shown in Table 3.8, which was based on the hypothesized learning progression in chemistry-based health literacy. However, initial analysis yielded poor fit to Rasch partial credit model. Hence, the rubric and learning progression was reviewed taking account the different answers of students during the pilot test. The revised learning progression is shown in Figure 3.8, and the revised rubric is shown in Table 3.9.

It was noted that in the pilot test, there were two sources of alternative conceptions. These were health-related alternative conceptions and chemistry concept-related alternative conceptions. This prompted the researcher to reorganize the learning progression and rubric used for evaluating student answers in order to adequately fit the Rasch partial credit model. The utilization of the initial rubric resulted to poor item fitting in the Rasch partial credit model. The rubric was modified by merging level 3 and level 4 in Table 3.8, which resulted to non-overlapping category curves for each level and better psychometric properties of the instruments as shown in Table 3.10.

**Table 3.9.**

*Final rubric for the evaluation of chemistry-based health literacy test*

| Level | Accuracy of Answer | Accuracy of Explanation | Type of Explanation | Score |
|---|---|---|---|---|
| 3 | Correct | Correct | Validated health claims linked to context-specific chemistry explanations presented via mechanistic reasoning | 3 |
| 2 | Correct | Correct | Validated health claims or health concepts linked to generalized chemistry concepts | 2 |
| 1 | Correct | Incorrect | Non-chemistry concepts or unrelated chemistry concepts | 1 |
| 0 | Incorrect | Incorrect | Non-chemistry concepts or unrelated chemistry concepts; no explanation | 0 |

Using the new rubric in Table 3.9, the responses were evaluated by two raters. The first rater was a BS Biology graduate pursuing Doctor of Medicine, while the second rater was an MS Biology graduate. Interrater correlation was determined to be 0.917 for 168 items. Items which were unclear were discussed via email. The raters for pilot test were also the raters during pretest and posttest. Consequently, the learning progression was also modified as shown in Figure 3.10.

It can be observed that the progression indicates a successful linking of chemistry concepts to health contexts since the characteristics of the population during pilot test ranged from health science students who did not take biochemistry yet, to students who have finished biochemistry and health-related professional subjects. In the pilot test the progression was from having no knowledge to novice or slightly better than novice. Hence, the progression represents the lower 3 levels in the original hypothesized learning progression in chemistry-based health literacy.

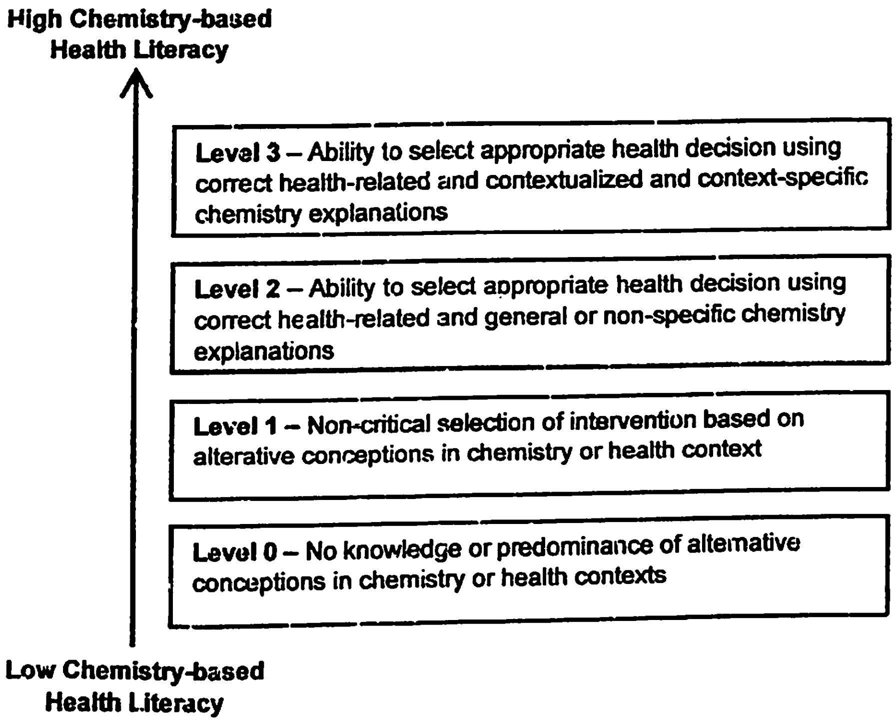


*Figure 3.10.* Revised hypothesized learning progression of chemistry-based health literacy

All correct answers in each item in the multiple-choice component were encoded as "0" for incorrect answers, and "1" for correct answers. All answers to "explanations" were coded using colors. The final codes were determined then subjected to Rasch partial credit model using WINSTEPS 4.4.5. Furthermore, Cronbach alpha was computed using SPSS 27.0.

The results of Rasch partial credit model indicated that five items did not fit the Rasch model based on fit statistics and were subsequently deleted from the test. After performing Rasch partial credit model using the 15 items, the model greatly increased in person separation and person reliability, and improved in item in terms of fit statistics (MNSQ and ZTSD) and unidimensionality. The results of final Rasch partial credit model of the 15 items are shown in Table 3.10. Prior to pretest, DIF analysis was further performed. It was found out that four items exhibited gender bias, and were deleted from the final form of the test. Hence, the final chemistry-based health literacy test had 11 items in total, composed of four items in nutrition (N1, N2, N3, and N4), three items in natural products (NP1, NP2, and NP3), two items in diagnostics (D1 and D2), and 2 items in pharmacology (P1, and P2). The specific items in chemistry-based health literacy test are presented in Appendix Q.

**Table 3.10.**

*Psychometric properties of chemistry-based health literacy test*

| Parameter | Results | Interpretation |
|---|---|---|
| Person separation | 2.09 | Person separation is good (Boone et al., 2014) |
| Person reliability | 0.81 | Person measures can discriminate 2 or 3 levels. |
| Item separation | 10.57 | There are 11 levels of difficulty. |
| Item reliability | 0.99 | Item difficulties have high reproducibility. |
| Fit statistics | | |
| Infit MNSQ | 0.94 to 1.05 | The items fit the dichotomous Rasch model. |
| Outfit MNSQ | 0.93 to 1.08 | ZTSD measures can be ignored if MNSQ values |
| Infit ZTSD | -1.01 to 0.90 | are within the acceptable range (Boone et al., |
| Outfit ZTSD | -1.16 to 1.29 | 2014) |
| Point measure correlation range | 0.42 to 0.59 | All items contribute to the measurement of the construct. |
| Unidimensionality | | |
| Eigenvalue of 1st contrast | 1.34 | The test is unidimensional. |
| PCA disattenuated correlation range | 0.87 to 1.00 | |
| Cronbach alpha* | 0.82 | The test has adequate internal consistency. |
| Person Measure | -4.04 to 1.49 | Items are within the person measure. |
| Item Measure | -1.13 to 0.89 | |
| Person and item mean difference | 0.70 | **Mean item difficulty is higher compared to the mean person ability logit. |

*analyzed using SPSS 27.0

**Mean item difficulty is 0.70 logit above the mean person ability logit

The threshold of categories in chemistry-based health literacy test is shown in Figure 3.11, indicating that the categories can be discriminated adequately using the Rasch partial credit model. Based on Figure 3.11, the Andrich thresholds at the intersections indicate that adjacent categories are probable on these intersections in the logit scale. Based on this information, category 0 is located below -1.19 logit, category 1 is located between -1.19 logit to 0.25 logit, Category 2 is between 0.25 to 0.95 logit and category 3 corresponds to values above 0.95 logit.

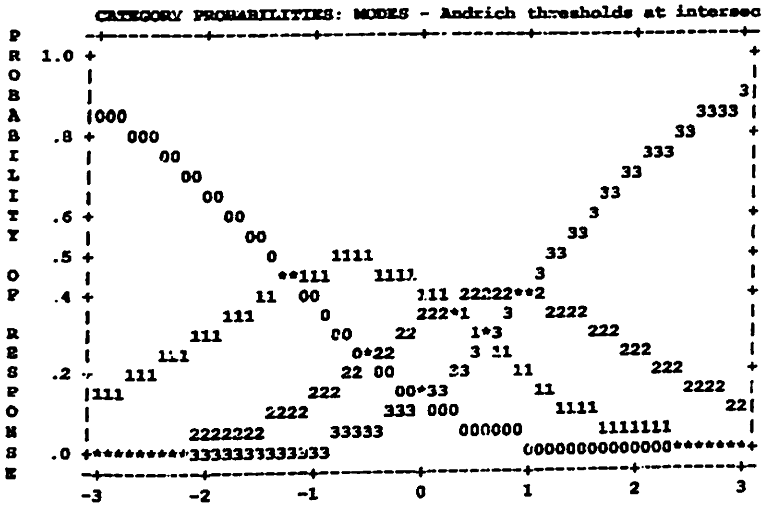


*Figure 3.11.* Rasch Andrich threshold of categories in chemistry-based health literacy

## Cognitive Load Questionnaire

The measurement of total cognitive load, intrinsic cognitive load, extraneous cognitive load and germane cognitive load in the QSAR activities were measured using a researcher-made questionnaire composed of 14 questions which were answered using a four-point Likert scale.

The scale to determine the level of agreement of the students is shown below:

1 – Strongly Disagree

2 – Disagree

3 – Agree

4 – Strongly Agree

In the cognitive load questionnaire (CLQ), items 1, 2 and 8 were related to intrinsic cognitive load. Items 3, 4, 5, 6, 7, 9 and 10 were related to extraneous cognitive load. Items 11, 12, 13 and 14 are related to germane cognitive load. Items 4, 6, 8, 10, 13 and 14 were scored in reverse. The scores were reversed because the highest rating in these items indicate lower endorsability of the construct being measured.

The first version of cognitive load questionnaire was evaluated by two PhD Chemistry professors and two PhD Chemistry Education professor. Based on item content validity indices, all items were acceptable. The research protocol for pilot testing of CLQ was submitted for ethics review las February 18, 2019. The protocol was approved last March 21, 2019 and was assigned with Protocol Number SLU-REC 2019-021.

After ethics approval, letters of communication were sent to a university in Baguio City for pilot testing. The results of the item content validity indices and content validation rating are shown in Appendix R and Appendix S, respectively. The procedure of obtaining item content validity and content validity rating was similar to the method used in prior knowledge of chemistry concepts test. The final cognitive load questionnaire is shown in Appendix M.

A dummy QSAR laboratory activity was prepared, and 384 second year BS Medical Technology respondents have answered the cognitive load questionnaire using the scale. All answers were encoded and transcribed in Microsoft Excel, then analyzed using Rasch rating scale model in WINSTEPS 4.4.5. Furthermore, Cronbach alpha was computed using SPSS 27.0. The results of analysis are shown in Table 3.11.

**Table 3.11.**

*Psychometric properties of cognitive load questionnaire*

| Parameter | Results | Interpretation |
|---|---|---|
| Person separation | 1.58 | Person separation is adequate (Boone et al., 2014) |
| Person reliability | 0.71 | Person measures can discriminate 1 or 2 levels. |
| Item separation | 11.59 | There are 12 levels endorsing cognitive load. |
| Item reliability | 0.99 | Item endorsing cognitive load have high reproducibility. |
| Fit statistics | | |
| Infit MNSQ | 0.85 to 1.24 | The items fit the dichotomous Rasch model. |
| Outfit MNSQ | 0.84 to 1.26 | ZTSD measures can be ignored if MNSQ values |
| Infit ZTSD | -2.16 to 3.41 | are within the acceptable range (Boone et al, |
| Outfit ZTSD | -2.38 to 3.71 | 2014) |
| Point measure correlation range | 0.35 to 0.58 | All items contribute to the measurement of the construct. |
| Unidimensionality | | |
| Eigenvalue of 1st contrast | 2.24* | The test indicates possible second dimension; but |
| PCA disattenuated correlation range | 0.20 to 0.67 | is still considered valid based on comparison with analysis of simulated data. |
| Cronbach alpha* | 0.74 | The test has adequate internal consistency. |
| Person Measure | -4.08 to 1.47 | Items are within the person measure. |
| Item Measure | -1.75 to 1.38 | |
| Person and item mean difference | 0.74 | Mean item difficulty is higher compared to the mean person ability logit |

*analyzed using SPSS 27.0

**Mean item difficulty is 0.74 logit above the mean person ability logit

The Andrich thresholds shown in Figure 3.12 indicates that the rating scale was appropriate.

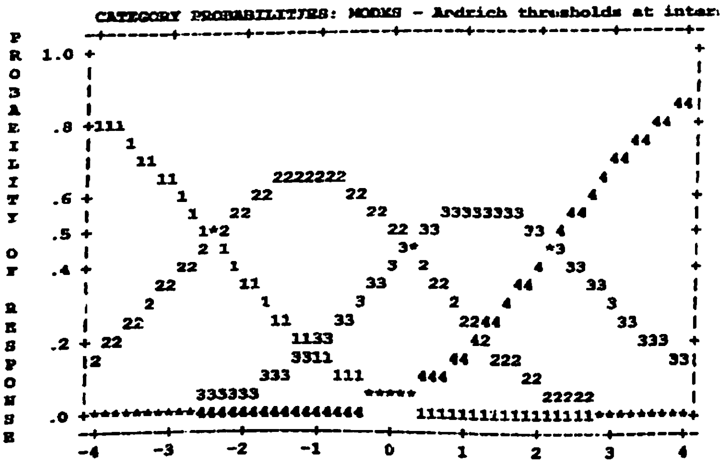


*Figure 3.12.* Rasch Andrich threshold of categories in cognitive load questionnaire

## Characteristics of Types of Instruction

Both mereology-based instruction and conventional instruction had similar number and type of activities. A total of six argumentation activity and six quantitative structure-activity relationship activities were performed during laboratory sessions. The theme of mereology-based instruction was *part-whole* relationship while the conventional instruction group utilized *structure-property/structure-function* relationship. The six quantitative structure-activity relationship activities were as follows:

*Activity 04 - Lipid Molecules and Radical Scavenging Assay (in silico + in vitro)*

*Activity 05 – E-ring Modified Steroids and 17β-Hydroxysteroid Dehydrogenase Type 1 Inhibition (insilico)*

*Activity 06 – Structure and Reducing Property of Saccharide Molecules (in silico + in vitro)*

*Activity 07 – Plant Metabolites and Porcine Pancreatic Amylase Inhibition (in silico + in vitro)*

*Activity 09 – In silico Analysis of Cytotoxic Nucleotide Analogues (in silico)*

*Activity 10 – Porcine Pancreatic Lipase Inhibition of Amino Acids and Dipeptides (in silico + In vitro)*

Table 3.12. summarizes the characteristics of mereology-based instruction and conventional instruction.

Table 3.12.

*Comparison of mereology-based instruction and conventional instruction*

| Characteristics | Mereology-based Instruction | Conventional Instruction |
|---|---|---|
| Approach | Part-whole relationship | Structure-property and Structure-function relationship |
| Components | Argumentation based on part-whole relationship<br>QSAR lab activities<br>Syllogisms | Argumentation based on structure-property and structure-function relationship<br>QSAR lab activities<br>Syllogisms |
| Topics | Characteristics of biochemical systems<br>pH and buffer<br>Structure and properties of simple and complex biomolecules<br>Enzyme structure, function and kinetics | Characteristics of biochemical systems<br>pH and buffer<br>Structure and properties of simple and complex biomolecules<br>Enzyme structure, function and kinetics |
| Duration (Lec) | Three meetings a week, one hour per meeting | Three meetings a week, one hour per meeting |
| Duration (Lab) | Three meetings a week, two hours per meeting | Three meetings a week, two hours per meeting |
| Grading System | Lec = 50% Exam + 50% CS<br>Lab = 30% exam + 45% CS + 25% LR<br>Combined Grade = 50% Lec + 50% Lab | Lec = 50% Exam + 50% CS<br>Lab = 30% exam + 45% CS + 25% LR<br>Combined Grade = 50% Lec + 50% Lab |
| Teaching Tools | Researcher-made laboratory manual<br>MolView, ChemDes, ChemMine, Microsoft Excel<br>Researcher-made lecture materials | Researcher-made laboratory manual<br>MolView, ChemDes, ChemMine, Microsoft Excel<br>Researcher-made lecture materials |

CS = Class standing; LR = laboratory report

The sequence of activities for mereology-based instruction and conventional instruction are presented in Figure 3.13. The sequence of activities for both instructional approaches is the same.

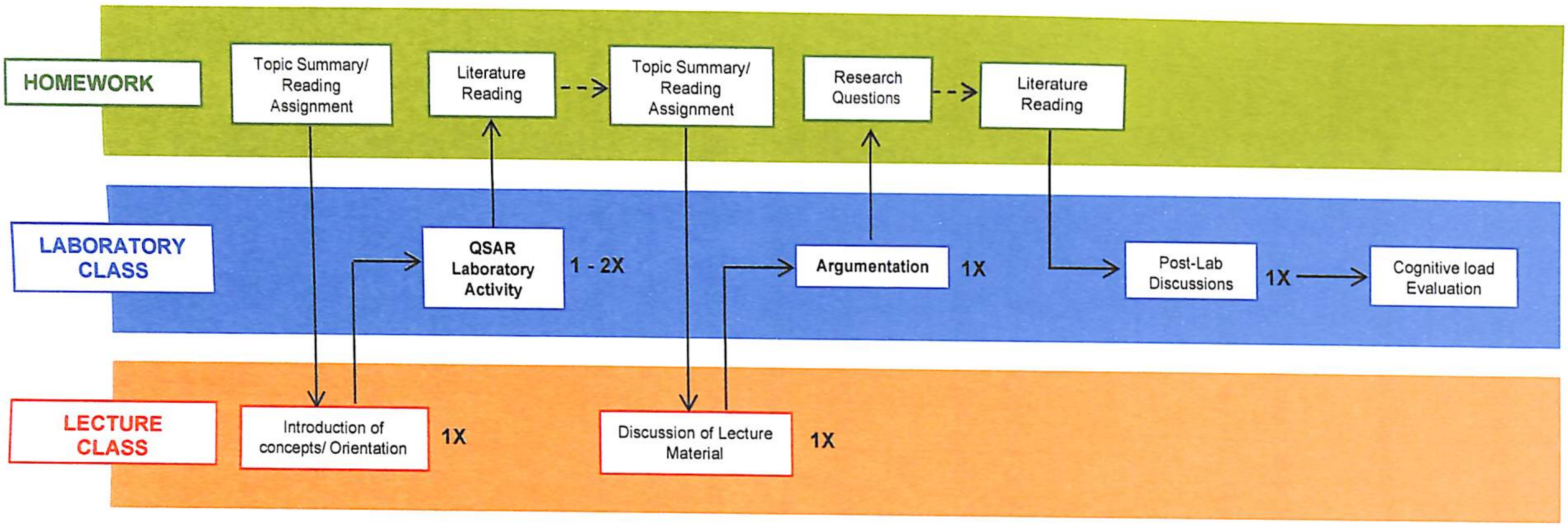


*Figure 3.13.* Sequence of activities in mereology-based instruction and conventional instruction
The QSAR laboratory report was evaluated using the Modified Hoyo Critical Thinking Evaluation Rubric for Laboratory Work Reports. Argumentation output was evaluated using a researcher-made rubric.

To illustrate the differences in the argumentation and research questions for students in the mereology-based instruction and the conventional instruction group, here are sample arguments from a similar quantitative structure-activity relationship.

***Activity 04: Lipid Molecules and Radical Scavenging Assay***

***Conventional Instruction:***

It is observed that L-ascorbic acid has a pi bond, and L-ascorbic acid has high radical scavenging activity. Is it logical to say that pi bonds contribute to radical scavenging activity of a product such as mango jam?"

***Mereology-based Instruction:***

L-ascorbic acid is a 'part' of a sample mango jam (whole). If L-ascorbic acid exhibits high radical scavenging activity, will the mango jam exhibit high radical scavenging activity as well?

The research questions for students after the QSAR activity were the same for both groups. For example, in Activity 04, the research questions were related to cardiovascular diseases, which is a leading cause of mortality in the Philippines.

**Research Question 1:** What are the roles of lipids in cardiovascular diseases?

**Research Question 2:** What is the role of radical scavenging activity to mitigation of cardiovascular diseases?

The details of the syllogisms and other questions given during argumentation for mereology-based instruction group and conventional instruction group are summarized in Table 3.13. Both groups had the same research questions in the laboratory manual. In activities 1 to 3, the students were immersed in activities which trained them in image analysis for analyzing a 96-well plate after performing Bradford assay, constructing linear regression using Microsoft Excel, quantifying an analyte in selected samples, determinizing Km and Vmax of an enzyme, and analysis of molecular descriptors using ChemDes, ChemMine and MolView. The students were also trained on how to write the laboratory reports, laboratory notebooks and construct arguments using the Toulmin Argumentation Pattern. This is to prepare them to the actual QSAR activities, which require all of the skills they have learned in the previous activities. In Activity number 5 (*E-ring Modified Steroids and 17β-Hydroxysteroid Dehydrogenase Type 1 Inhibition (in silico)*, students were required to develop a multiple linear regression to determine the molecular descriptors which could describe the optimal inhibitor to the enzyme *17β-Hydroxysteroid Dehydrogenase Type 1.*

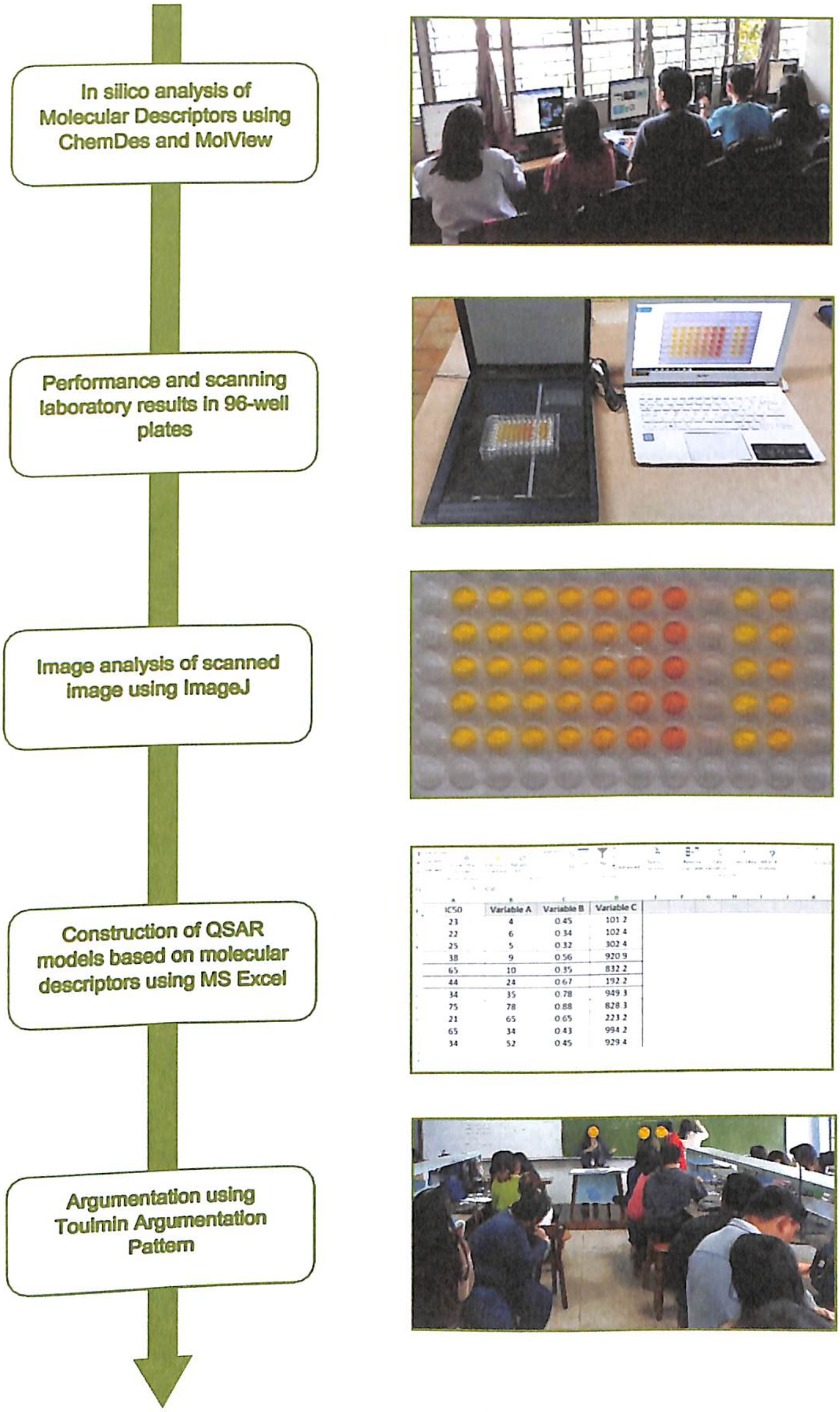
In Activity 6 (*Structure and Reducing Property of Saccharide Molecules)*, students performed an activity which required the identification of a reducing sugar based on a quantitative Benedict's test suing image analysis and multiple linear regression models. In Activity 7 (*Plant Metabolites and Porcine Pancreatic Amylase Inhibition*) students were instructed to determine the molecular descriptors which contributes to the inhibition of the enzyme lipase using image analysis. In Activity 9 (*In silico Analysis of Cytotoxic Nucleotide Analogues*), students determined the molecular descriptors which contribute to in vitro cytotoxicity.

Lastly, in Activity 10 (*Porcine Pancreatic Lipase Inhibition of Amino Acids and Dipeptides*), students determined the molecular descriptors of dipeptides which contributes to the inhibition of porcine pancreatic lipase. All of the procedures, activities and research questions are the same for the mereology-based instruction and conventional instruction groups. Only the argumentation activity is different, as the arguments in mereology-based instruction were based on a *part-whole* relationship, while the argumentation in the conventional instruction group was based on structure-property or structure-function relationship.

Table 3.13. Summary of argumentation and research questions in MBI and CI group

| Laboratory Activity | Argumentation Activity | | Research Questions (Similar for both groups) |
|---|---|---|---|
| | Mereology-based Instruction | Conventional Instruction | |
| *E-ring modified steroids and 17β-hydroxysteroid dehydrogenase Type 1 Inhibition* | A steroid molecule exhibits dehydrogenasetype 1 inhibition. The steroid molecule is a 'part' of polymer X. Therefore, polymer X will exhibit dehydrogenase type 1 inhibition. | What are the effects of the various substituents attached to the 17th positionof the steroid ring to the inhibition of dehydrogenase type 1? | In it advisable for women to be screened for estrogen-estradiol levelsas a diagnostic parameter diagnosing estrogen-related cancers? Why or why not? |
| *Structure and reducing property of saccharide molecules* | A monosaccharide has several hydroxyl groups (-OH) 'parts'. The monosaccharide exhibits reducing properties. Replacing all hydroxyl groups with amino groups causesloss of reducing properties. | What is the role of the anomeric carbonto the reducing property of monosaccharides and some disaccharides? | Is the quantitative Banedict's test a reliable method to diagnose Diabetes mellitus using urine samples? Why orwhy not? |
| *Plant metabolites and porcine pancreatic amylaseInhibition* | Phenolic molecule A exhibits amylase inhibition *in vitro*. Phenolic molecule A is apart of Molecule ABC. Therefore, Molecular ABC has amylase inhibition. | What is the relationship between the molecular structure of the secondary metabolite to the inhibition of porcine pancreatic amylase? | Is amylase inhibition a better alternative to insulin injection when managing Diabetes mellitus? Why orwhy not? |
| *In silico analysis of cytotoxic nucleotide analogues* | A purine nucleotide analogue exhibits *in vitro* cytotoxic property. A purine nucleotidehas higher molecular weight than a nucleoside analogue due to an additional 'part'. Therefore, the nucleoside analogue will exhibit lesser *in vitro* cytotoxic property. | What is the relationship between molecular structures of purine nucleotideanalogues and their *in vitro* cytotoxic activities? | Are nucleotide analogues potential alternatives to target specific tumorsin the body? Why or why not? |
| *Porcine Pancreatic Lipase Inhibition of Amino Acids and Dipeptides* | The tetrapeptide FYHC exhibits pancreatic lipase inhibition. Tetrapeptide CHYF is composed of the same amino acid as FYHC. Therefore, the tetrapeptide CHYF also exhibits the same magnitude of pancreatic lipase inhibition. | How does the molecular structure of dipeptides, tripeptides and tetrapeptides influence their ability to inhibit porcine pancreatic lipase? | Is the utilization of lipase inhibition data in clinical studies an effective approach to address health concernsrelated to all cardiovascular diseases? Why or why not? |

Figure 3.14 shows the sequence of activities in the laboratory session. The methods used in the laboratory activities were analyzed for reliability in February to June 2019. Image analysis was compared to spectrophotometric analysis and method optimization was performed using image analysis. The limit of quantitation, limit of detection and coefficient of determination were determined for the image analysis procedure and were compared to spectrophotometric methods. The methods, choice of scanner, and repeatability of results in enzyme kinetics assays using porcine lipase and porcine alpha amylase were also determined in three to four replicates. The laboratory reagents were purchased by the researcher and dispensed in "lab kits" for each group. The lab kits contained all required materials for QSAR each activity.



| IC50 | Variable A | Variable B | Variable C |
|---|---|---|---|
| 23 | 4 | 0.45 | 101.2 |
| 22 | 6 | 0.34 | 102.4 |
| 25 | 5 | 0.32 | 302.4 |
| 38 | 9 | 0.56 | 920.9 |
| 65 | 10 | 0.35 | 832.2 |
| 44 | 24 | 0.67 | 192.2 |
| 34 | 35 | 0.78 | 949.3 |
| 75 | 78 | 0.88 | 828.3 |
| 21 | 65 | 0.65 | 223.2 |
| 65 | 34 | 0.43 | 994.2 |
| 34 | 52 | 0.45 | 929.4 |

*Figure 3.14.* Sequence of activities in the biochemistry laboratory

## Data Collection Procedure

The approved research protocol was submitted for ethics review last February 18, 2019 and approved last March 25, 2019 with an ethics approval certificate SLU-REC 2019-021. Please see approved research ethics protocol in Appendix N. Upon approval, a preliminary survey was conducted at Saint Louis University to collect information such as course syllabus, profile of the school, profile of the students, and teaching-learning dynamics. A five-day training-workshop was conducted last July 22, 2019 to seven prospective Biochemistry instructors to train them on how to use MolView, ChemDes, statistical analysis in Microsoft Excel, performance of laboratory assays, and evaluation of written arguments using Toulmin Argumentation Pattern (Appendix O). The Biochemistry instructors were also oriented on how to use the lecture learning material and laboratory manual. Two versions of the laboratory manual were developed, and the main difference is the theme used in the argumentation part.

Prior to pretest of the research instruments during the second week of August 2019, an informed consent (Appendix P), indicating the purpose of the study, was obtained from all students during the first week. After signing the informed consent form, the students were requested to submit the signed informed consent form to their teacher. After submitting the informed consent forms, five research instruments (prior knowledge of chemistry concepts, visual representations test, chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy test) were floated to the participants.

After taking the pretest, all participants underwent one week of orientation and workshop on how to obtain molecular descriptors from ChemDes, and how to interpret skeletal diagrams and ball and stick models from MolView in the university library. The training was facilitated by the researcher and the Biochemistry instructors who underwent training. Two meetings were used to train students on how to perform image analysis using ImageJ using results from Bradford assay. The third week of August 2019 was the actual start of the intervention in both mereology-based instruction and conventional instruction groups. After every QSAR activity, the cognitive load questionnaire was floated. Posttest answers to chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy were obtained during the last week of November 2019.

## Determination of Rasch Analysis Parameters

### Person and Item Reliability and Separation

In contrast to the use of Cronbach's alpha and KR-20 for many analyses, Rasch analysis provides person and item separation and reliability. Both Cronbach's alpha and KR-20 are based on raw scores, which are non-linear (Boone et al., 2014). Person reliability, however, may be interpreted as analogous, but not similar to Cronbach's alpha or KR-20. The person reliability is tentatively interpreted using the following guideline: 0.90 = 3 or 4 levels, 0.80 = 2 or 3 levels, and 0.5 = 1 or 2 levels. The number of ability strata which can be resolved is provided by the formula (4G + 1)/3 with the assumption that different ability levels are 3 standard errors apart (Planinic et al., 2019).

Item reliability, on the other hand, indicates the repeatability of measures of the items. High reliability simply means that the data are reproducible, but the quality of the test depends also on the quality of its items and the degree to which they define a meaningful construct (Planinic et al., 2019).

Separation coefficient or index is the ratio of the person (or item) "true" standard deviation to the error standard deviation. The person separation index identifies the strata of abilities identified in the sample group, and the acceptable value is >2.0 (Linacre, 2012). Hence, a person separation index is used to classify people. Low person separation with a relevant person sample implies that the instrument may not be sensitive enough to distinguish between high and low performers, and may require more items in the test. Item separation is used to verify item difficulty hierarchy, and should be >3.

### Fit Statistics

The fit statistics in Rasch analysis describes the fit or appropriateness of the items to the Rasch model. For the mean square fit statistics (MNSQ), the expected value of the chi-square distribution is 1. If the value is greater than 1, it implies a variation between the model and the observed score. A fit statistic of 1.30, for example, implies 30% variation or noise than the predicted Rasch model, which characterizes an underfit with the model. Similarly, a fit statistics value of 0.70, implies 30% less variation than the predicted model, and implies an overfit with the model. In this study, the MNSQ value threshold will be acceptable if MNSQ is within 0.70 to 1.30. This also ensures that the model will have adequate unidimensionality (Smith et al., 2008).

The two mean square fit statistics are infit mean square (also referred to as the weighted mean square) and outfit (or unweighted) mean square. Both mean squares are derived from the squared standardized residuals for each item and person interaction. Outfit and infit statistics can also be evaluated using the ZSTD values, where ZSTD is a normalized Z score of the residual. The range of infit and outfit ZSTD should be within -2 to +2 to have a good model fit (Planinic et al.,2019). A poor fit of items may indicate problems with the item's structure, wording, scoring and content.

### Item Difficulty

The item difficulty was examined by comparing the item difficulty hierarchy between the results of dichotomous Rasch analysis and partial credit model, according to a hypothesized item difficulty hierarchy, to determine whether the instrument endorses the proposed construct being investigated. If the hypothesized item hierarchy is supported by the item hierarchy after performing Rasch analysis, then the research instrument has adequate construct validity. The item difficulty hierarchy was presented using a Wright map, or a person-item map. A Wright map utilizes the difficulty of test items and expresses them using the same linear scale that is used to express a student's performance or person measure (Boone, 2016).

### Unidimensionality

Unidimensionality ensures that only one construct is measured by a research instrument. In Rasch analysis, unidimensionality is measured using an analysis of the variance explained by the first dimension, or by using the eigenvalues of the unexplained variance of the first contrast. A research instrument should have an eigenvalue of $\geq 2$ to ensure that the instrument measures one construct (Boone & Staver, 2020). Additionally, the item correlation (point measure correlation) results should be positive values to indicate that all items are measuring the same construct underlying a research instrument.

## Data Analysis Procedure

All data were first converted into logits using dichotomous Rasch analysis for prior knowledge of chemistry concepts test and visual representations test and Rasch partial credit model for chemical identity thinking instrument, critical thinking test in chemistry and chemistry-based health literacy test. For the answers to cognitive load questionnaire, data was converted into logits using Rasch rating scale model.

Student ability logits and item difficulty logits were presented individually in figures and tables, or simultaneously using Wright map for stacked and racked analysis. Mean item difficulties per topic were obtained by obtaining the average of item difficulty logits in Rasch analysis and presented as mean ± standard deviation.

To obtain pretest-posttest changes in chemical identity thinking instrument, critical thinking test in chemistry and chemistry-based health literacy, two analyses were performed. Stacked analysis was performed to determine changes in student ability while racked analysis was performed to determine changes in item difficulty. Stacking and racking procedures in Rasch analysis were performed to provide an accurate measure of student ability changes and item difficulty changes, as shown by the following studies: Boone & Scantlebury, 2006; Combrinck et al., 2016; Herrmann-Abell & De Boer, 2017).

Rasch learning gains were obtained by simply getting the difference between individual and mean posttest student ability logits and pretest student ability logits (Nitta & Aiba, 2019; Pentecost & Barbera, 2013). All student ability logits were presented as mean ± standard deviation in figures or tables. Statistically significant differences were indicated using letter codes.

To determine significant differences in the posttest ability logits of students in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy, analysis of covariance (ANCOVA) was performed using pretest student ability logits, and student ability logits in prior knowledge of chemistry concepts test and visual representations test as covariates. Effect size was determined using partial eta squared ($\eta p^2$). According to Fritz et al. (2012), effect size using partial etasquared may be small (>0.01), medium (>0.06) or large (>0.14). Similar to the studyof Vidak et al. (2018), if ANCOVA assumptions are not met particularly on homogeneity of variance, ANCOVA was still utilized in this study to determine the significance in the difference in posttest logits.

To determine differences in Rasch learning gains in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy, analysis of covariance (ANCOVA) was performed using the pretest student ability logit in chemical identity thinking instrument, critical thinking in chemistry test, and chemistry-based health literacy test as covariance of Rasch learning gains. Effect size was determined using partial eta squared ($\eta_p^2$).

To determine significant predictors of posttest student ability in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy, multiple linear regression was performed using pretest student ability (logit) in chemical identity thinking instrument, critical thinking test in chemistry, and chemistry-based health literacy test, student ability logits in prior knowledge of chemistry concepts, visual representations test, and cognitive load questionnaire, and gender. Effect size was determined using Cohen's $f^2$. According to Selya et al. (2012), effect size using Cohen's $f^2$ may be small, moderate ($f^2 \geq 0.15$) to large ($f^2 \geq 0.35$).

All statistical analyses were performed using IBM SPSS 27.0 for Windows, with α level set at 0.05. For the sample output of statistical analyses, please refer to Appendix X.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

The goal of the study is to compare the effects of mereology-based instruction and conventional instruction to the chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy based on measures for student ability and item difficulty in the Rasch model. In this study, the changes in person ability logit units and item difficulty logit units are used to compare the effects of mereology-based instruction to conventional instruction in biochemistry.

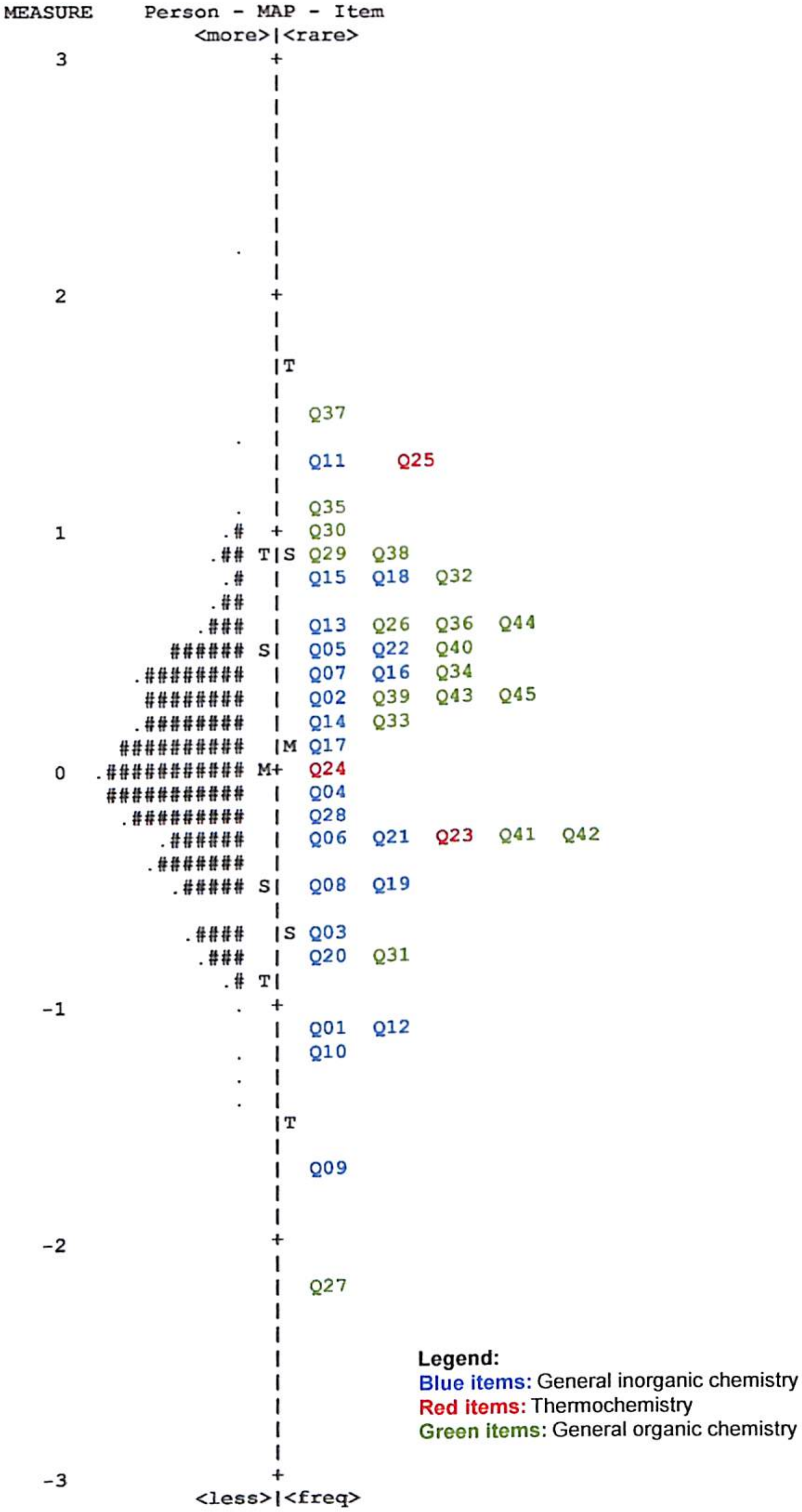
The student ability and item difficulty logit were obtained using dichotomous Rasch analysis for prior knowledge of chemistry concepts (PKCC) and for prior knowledge of visual representations (PKVR). The Rasch partial credit model was used for chemical identity thinking (CIT), critical thinking in chemistry (CTC), and chemistry-based health literacy (CbHL) and the Rasch rating scale model for determining cognitive load (CL). This chapter presents the results and discussions based on the sequence of research problems presented in Chapter 1.

## Level of Item Difficulty of Prior Knowledge of Chemistry Concepts Test and Visual Representations Test

### Item Difficulty of Prior Knowledge of Chemistry Concepts Test (PKCCT)

The Wright map in Figure 4.1 illustrates the difficulty of all items in prior knowledge of chemistry concepts test alongside the student abilities. Based on the mean student ability and mean item difficulty (indicated by M on both sides of the linear scale), the difference is 0.11 logit, indicating a proper targeting of the research instrument due to the proximity of the means. This implies that the instruments are neither too difficult nor too easy for the participants (Boone, 2016; Boone & Staver, 2020). There also gaps in the items, but these are less than 0.50 logit. All items are also within 1 logit from all student abilities, indicating that all items are not too difficult nor too easy for the target participants.

Out of the 45 items in the prior knowledge of chemistry concepts test (PKCCT), 17 items were below the mean person ability, indicating that most items are actually difficult to most students. In addition, mean item difficulty was slightly higher than mean student ability, indicating that the test difficulty is appropriate for the participants in this study. The most difficult item was **Q37** (aromaticity), while the easiest item was **Q27**. Items which assess higher order thinking skills (**Q11**, **Q15**, **Q18**. **Q13**, **Q05** and **Q22**) generally had higher item difficulty while items which have lower item abilities involve recalling of information (**Q09**, **Q11**, **Q12** and **Q22**). For the details of each item, please refer to Appendix E.



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                     |  Q11      Q25
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                  .  |  Q35
    1            .#  +  Q30
                .## T|S Q29    Q38
                 .#  |  Q15    Q18    Q32
                .##  |
               .###  |  Q13    Q26    Q36    Q44
             ###### S|  Q05    Q22    Q40
          .########  |  Q07    Q16    Q34
           ########  |  Q02    Q39    Q43    Q45
          .########  |  Q14    Q33
         ##########  |M Q17
    0  .########### M+  Q24
        ###########  |  Q04
         .#########  |  Q28
            .######  |  Q06    Q21    Q23    Q41    Q42
           .#######  |
             .##### S|  Q08    Q19
                     |
              .####  |S Q03
               .###  |  Q20    Q31
                 .# T|
   -1             .  +
                     |  Q01    Q12
                  .  |  Q10
                  .  |
                  .  |
                     |T
                     |
                     |  Q09
                     |
                     |
   -2                +
                     |
                     |  Q27
                     |
                     |
                     |
                     |
                     |
                     |
                     |
   -3                +
               <less>|<freq>
```

**Legend:**
**Blue items:** General inorganic chemistry
**Red items:** Thermochemistry
**Green items:** General organic chemistry

Each "#" is 5 persons: Each "." is 1 to 4 persons

*Figure 4.1.* Wright map of cumulative data in prior knowledge of chemistry concepts test

Note: Vertical line divides person ability (left side) and item difficulty (right side). Lowest item in the logit scale is the least difficult while highest item is the most difficult. Lowest person has the least ability while the highest person has the highest ability. Item difficulties were obtained when mean person ability is set at 0

When items are combined based on topics, it is shown in Figure 4.2 that items related to general organic chemistry (**GOC**) concepts were more difficult for students (N=21, M=0.36, SD=0.81), with the exception of nomenclature of alkene (**Q27**). Items which were related to general inorganic chemistry (**GIC**) concepts had lower item difficulties (N=21, M =-0.13, SD=0.78) than items which were related to basic thermochemistry (**TC**) concepts (N=3, M=-0.07, SD=0.41).

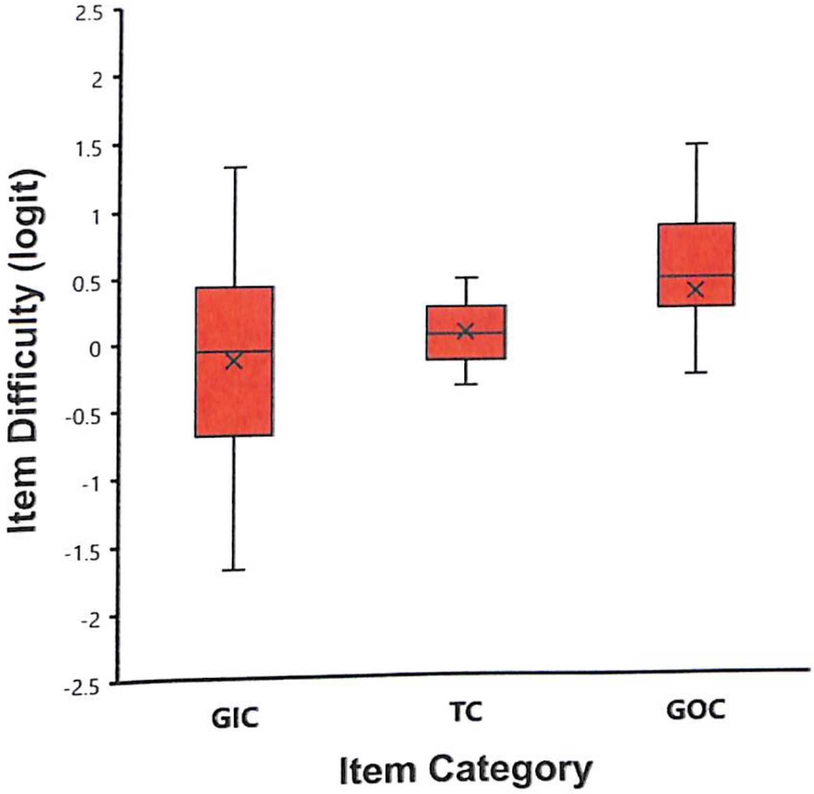
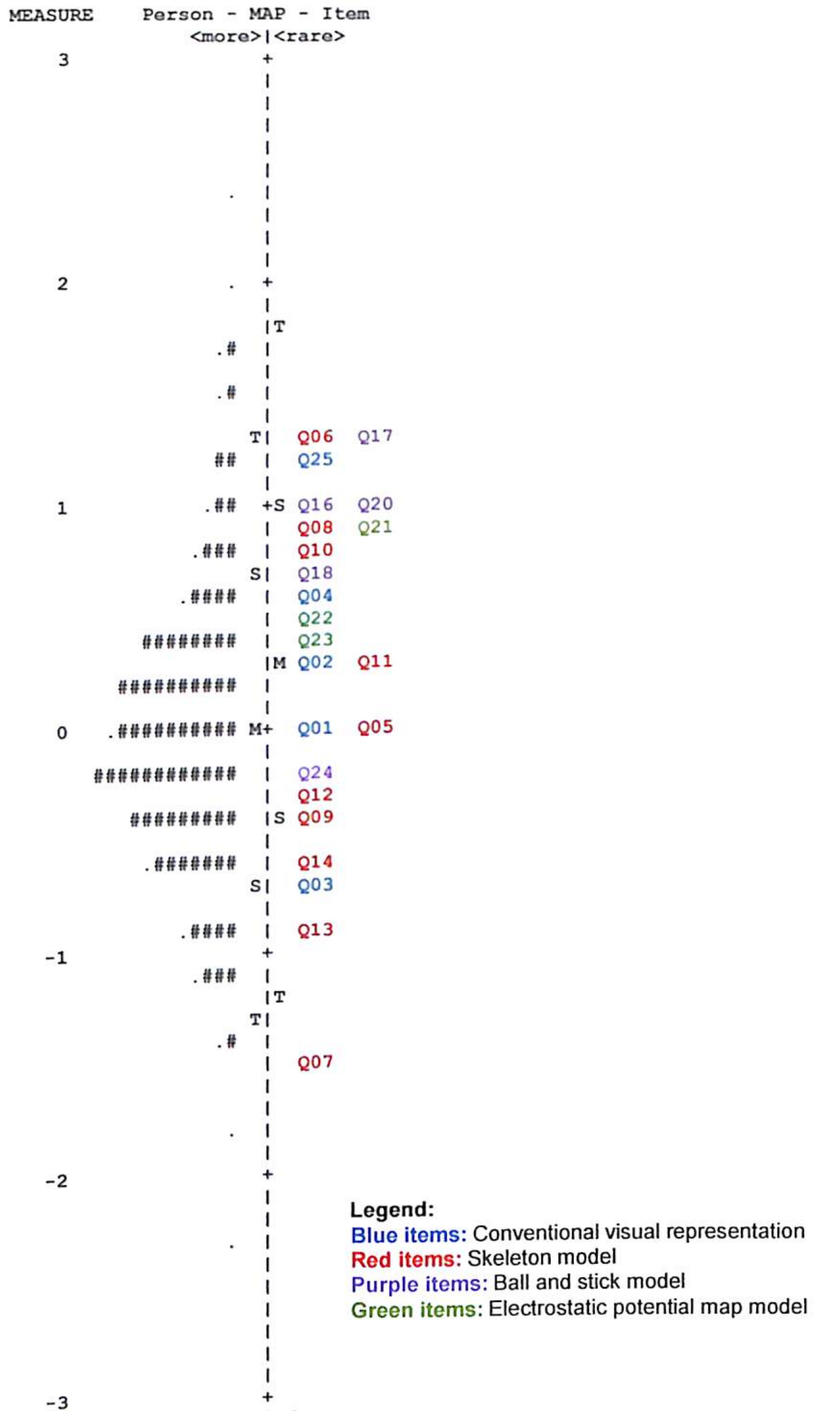


*Figure 4.2.* Mean difficulty of items in prior knowledge of chemistry concepts test
GIC = general inorganic chemistry, TC = thermochemistry, GOC = general organic chemistry

### Item Difficulty of Visual Representations Test

The Wright Map of combined data for all students is presented in Figure 4.3. Based on the data, the mean item difficulty is 0.29 (SE = 0.09), relative to the mean of student ability which is set at zero logit. Out of the 23 items in the test, seven items were below the mean person ability. All items were within the range of student abilities. The most difficult items were **Q08** and **Q19** while the easiest item was item **Q07**. Please refer to Appendix 3.8 for the details of each item.



```
MEASURE     Person - MAP - Item
                <more>|<rare>
    3                 +
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    2              .  +
                      |
                      |T
                  .#  |
                      |
                  .#  |
                      |
                     T|   Q06  Q17
                  ##  |   Q25
                      |
    1            .##  +S  Q16  Q20
                      |   Q08  Q21
                .###  |   Q10
                     S|   Q18
               .####  |   Q04
                      |   Q22
            ########  |   Q23
                      |M  Q02  Q11
          ##########  |
                      |
    0    .########## M+   Q01  Q05
                      |
        ############  |   Q24
                      |   Q12
           #########  |S  Q09
                      |
            .#######  |   Q14
                     S|   Q03
                      |
               .####  |   Q13
   -1                 +
                .###  |
                      |T
                     T|
                  .#  |
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                      |
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                      |
                      |
                      |
   -3                 +
                <less>|<freq>
```

**Legend:**
**Blue items:** Conventional visual representation
**Red items:** Skeleton model
**Purple items:** Ball and stick model
**Green items:** Electrostatic potential map model

Each "#" is 7 persons: Each "." is 1 to 6 persons

*Figure 4.3.* Wright map of combined data in visual representations test.

Note: Vertical line divides person ability (left side) and item difficulty (right side). Lowest item in the logit scale is the least difficult while highest item is the most difficult. Lowest person has the least ability while the highest person has the highest ability in the logit scale.

When items are combined into topics, Figure 4.4. shows that items related to ball and stick models were the most difficult based on mean item difficulty (N = 4, M = 0.99, SD = 0.24). The mean difficulty of items related to EPM models (N = 3, M = 0.61, SD = 0.29) was higher compared to the mean item difficulty of items related to skeletal models (N = 10, M = -0.05, SD = 0.86) and conventional visual representations (N = 6, M = 0.21, SD = 0.65).

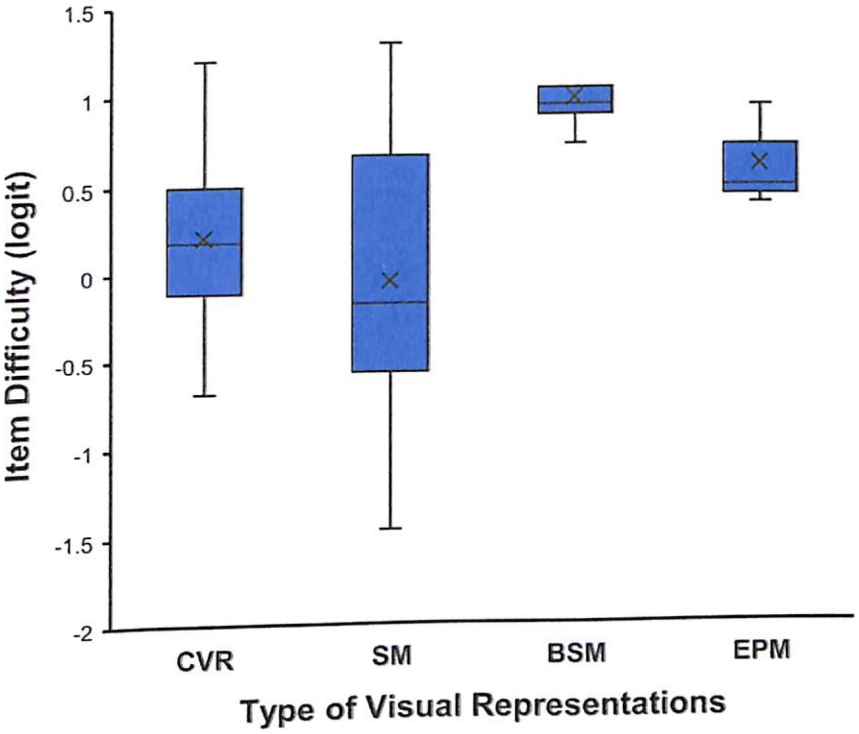


*Figure 4.4.* Mean difficulty of items in visual representations test
CVR = conventional visual representations, SM = skeletal model; BSM = ball and stick model, EPM = electrostatic potential map

The data suggests that students who are enrolled in biochemistry have varying degrees of prior conceptual knowledge about chemistry concepts and visual representations. Note that item difficulties are presented in a Wright map. In this type of figure, a student measure (marked by "#" or ".") is laid in the same scale as item difficulty. If a person measure is in the same logit as an item, the probability of success of answering the item is 50%. If the item measure is higher than student ability, it means that the probability of answering the item becomes less than 50%. If the item measure is lower, then the probability of the student answering the item correctly is more than 50%.

In the prior knowledge of chemistry concepts results, it was evident that the most difficult items were generally related general organic chemistry concepts (GOC) while the easiest items are generally related to general and inorganic chemistry concepts. This reflects the chemistry concepts which were effectively recalled by students prior to enrolling biochemistry. Since general and inorganic chemistry concepts were introduced since high school, the concepts have been retained quite effectively. Furthermore, the bulk of discussions in the general inorganic chemistry and organic chemistry subjects of the students are more focused on general inorganic chemistry concepts.

In contrast, the item difficulties of general organic chemistry concepts are generally higher because the topics in organic chemistry are not typically discussed in detail since the concepts are cramped up in one month during the final term of the semester. It is possible that students were unable to effectively recall and apply the general organic chemistry concepts in answering the research instrument. However, it remains clear that regardless of concepts, all items which require higher order thinking skills are generally more difficult for students.

The depth to which each topic is approached was reported by Silva and Batista (2003) to be dependent on the students' undergraduate area and prior knowledge. The same is assumed when learning biochemistry concepts, since general, inorganic chemistry and organic chemistry are prerequisite subjects among health science students. However, health science programs may be a special case since the program requires a multidisciplinary approach in learning health concepts. While it was previously reported that there is no influence of background knowledge in biology and chemistry to learning biochemistry (Minasian-Batmanian et al., 2006), it is argued in this study that prior knowledge in chemistry is an important factor to determine the trajectory of learning of students in biochemistry, as biochemistry concepts build on prior conceptual understanding of chemistry concepts. Prior knowledge of previous courses contributes to learning of more complex courses such as biochemistry, and this is also true to health professional courses (Hailikari et al., 2008).

With regards to prior knowledge of visual representations, the most difficult items were related to ball and stick models while the easiest items were related to skeletal structures or skeletal models. The results are not surprising in the health care sciences since organic chemistry concepts are only discussed during the final term of the semester, and most representations such as ball and stick models, skeletal structures and electrostatic potential maps are only introduced during the discussion of organic chemistry concepts. The skeletal structures were relatively easier for students due to their familiarity about the model, which was already introduced during high school. Furthermore, the concept about skeletal structures is reinforced during the chemistry courses of the health science students prior to enrolling their biochemistry subject.

As argued in this study, the students' prior knowledge of visual representations should be determined because biochemistry deals with more complex visual representations. Some visual representations in biochemistry focused on simple structural features of biological molecules (Harle & Towns, 2013; Li & Koehl, 2014;

Linenberger & Bretz, 2014; Mnguni et al., 2016). However, it is also common for visual representations to focus on other dynamic chemical features such as molecular interactions and processes (Bussey & Orgill, 2015). The main goal of these studies is to ensure learning of chemistry content by using sub-microscopic representations.

The differences in the difficulty of items related to various visual representations may also be attributed to the cognitive requirement when decoding or interpreting the information provided by the model. The ball and stick model might be difficult for students to interpret since it requires manipulation to avoid ambiguities while the items in the test are presented as two-dimensional structures that do not permit manipulation. It was stressed by Offerdahl et al. (2017) that the features of visual representations have different levels of abstraction because visual representation only presents a specific structural feature of the molecule or a specific process that is observed from a chemical reaction. Ball and stick models require substantial amount of prerequisite knowledge compared to skeletal models and particle models, justifying that indeed, these representations were more difficult for health science students.

It was also expected that skeletal structures are less difficult for most students compared to ball and stick models since this visual representation is repeatedly used when teaching nomenclature and students during high school. Furthermore, skeletal structures are used again when teaching organic chemistry concepts in tertiary level chemistry subjects. Note that the easiest item in the prior knowledge of chemistry concepts involves nomenclature of an alkene using its skeletal structure.

In summary, learning biochemistry concepts requires application of previously learned chemical concepts and visual representations to understand the molecular context of biological concepts (Villafañe et al., 2011). Since simple and complex biomolecules are treated as organic molecules, failure to understand organic chemistry concepts and visual representations may compromise learning of biomolecules and the molecular interactions in the chemical environment of the cell. However, a poor performance in organic chemistry does not automatically result to poor achievement in biochemistry (Wright et al., 2009). Hence, there is still a need to establish whether the type of chemistry instruction in the health sciences influence their succeeding performance in their professional courses.

## Differences in Chemical Identity Thinking, Critical Thinking in Chemistry and Chemistry-based Health Literacy

### Student Ability Differences in Chemical Identity Thinking

Table 4.1 shows that students in the mereology-based instruction group and conventional instruction group had an increase in their posttest student ability logits. Generally, male students in both groups had a higher mean pretest ability logit compared to female students. During posttest, male students in the mereology-based instruction group had the highest ability logit, followed by male students in the conventional instruction group. Female students in the mereology-based instruction group also had higher posttest ability logit than female students in the conventional instruction group.

**Table 4.1.**

*Pretest and posttest student ability in chemical identity thinking instrument*

| Group | Gender | Mean Student Ability | |
|---|---|---|---|
| | | Pretest | Posttest |
| **Mereology-based instruction** | Male | -0.304$^a$ (0.485) | 0.302$^a$ (0.691) |
| | Female | -0.501$^b$ (0.556) | -0.047$^b$ (0.532) |
| **Conventional Instruction** | Male | -0.301$^a$ (0.542) | -0.015$^b$ (0.455) |
| | Female | -0.419$^a$ (0.549) | -0.072$^b$ (0.380) |

Means are expressed with SD. Means with different letters indicate statistically significant difference at $\alpha$=0.05. Mean pretest abilities significantly differ, $p$=0.016. All items fit the Rasch partial credit model.

After controlling for ability logit in prior knowledge of chemistry concepts, there was a significant effect of type of intervention to the posttest mean ability logit of male and female students, $F_{(5, 537)} = 5.537$, $p=0.002$, $\eta_p^2=0.028$. After controlling for ability logitin prior knowledge of visual representations, there was a significant effect of type of intervention to the posttest mean ability logit of male and female students, $F_{(5, 537)} = 6.281$, $p = 0.002$, $\eta_p^2=0.032$. It should be noted that the effect sizes were small, indicating that after controlling for the covariates, the variance in the posttest ability was accounted for by the type of instruction by 2.8% to 3.2%.

Pairwise comparisons revealed that male students in the MBI group had significantly higher posttest mean ability logit compared to other students after controlling for prior knowledge of chemistry concepts, prior knowledge of visual representations, and pretest student ability logits. The mean posttest ability logit of male students in the conventional instruction group was not significantly higher than the female students in either mereology-based instruction group and conventional instruction group after controlling for the three covariates.

The result in the gender differences in student ability logits of students in chemical identity thinking agrees with the report that male students have generally higher achievement in chemistry (Forbes-Lorman et al., 2016; Rauschenberger & Sweeder, 2010; Veloo et al., 2015). Since the chemical identity thinking instrument is designed to measure an increasing sophistication of explanations to differentiate substances, the gender differences in pretest and posttest student ability logits may be attributed to the ability of male and female students select appropriate attributes or properties of substances to emphasize the unique identity of substances. However, it is asserted that gender differences in chemical identity thinking may be attributed to learning characteristics, readiness and motivation of students in the target institution, and not gender *per se*.

The dispersion of student ability logits, as revealed by the standard deviations of the means indicate that the pretest and posttest abilities of students in both mereology-based instruction and conventional instruction are diverse. This suggests that careful analysis should be done to determine the changes in the levels of chemical identity thinking among students. This also justifies the need to investigate changes in item difficulties for both groups, which are discussed comprehensively in the succeeding sections.

The item difficulty of chemical identity thinking decreased during posttest, as shown by a decrease in item difficulty logits (Figure 4.5). Specifically, fourteen items have decreases in item difficulty by more than 0.50 logit in the mereology-based instruction group. A 0.50 difference between student ability and item difficulty implies 62% probability of students answering these items correctly based on the logit to probability conversion table (https://www.winsteps.com/winman/whatisalogit.htm).

These items include ten biochemistry topics (**Q02**, **Q03**, **Q04**, **Q05**, **Q07**, **q03**, **q05**, **q08**, **q09** and **q10**), two organic chemistry topics (**Q01** and **Q06**), and two general inorganic chemistry topics (**Q09** and **Q10**). On the other hand, nine items decreased in item difficulty by more than 0.50 logit during posttest in the conventional instruction group. These items include seven biochemistry topics (**Q02**, **Q04**, **Q07**, **q01**, **q02**, **q04**, **q08** and **q10**) and two organic chemistry topics (**Q07** and **q07**). Please refer to Appendix K for the details of each item.

A decrease in item difficulty among different items from pretest to posttest indicates that these items became easier for students to answer. In addition, the decrease in item difficulty also indicates an increased accuracy and sophistication of explanations when differentiating substances or mixtures. While it is true that item difficulty changes reveal an improvement in the construct being measured, careful interpretation should be done when comparing the students in the mereology-based instruction group and conventional instruction group since the items which decreased in item difficulty were different, and the magnitude of item difficulty changes are different per item.

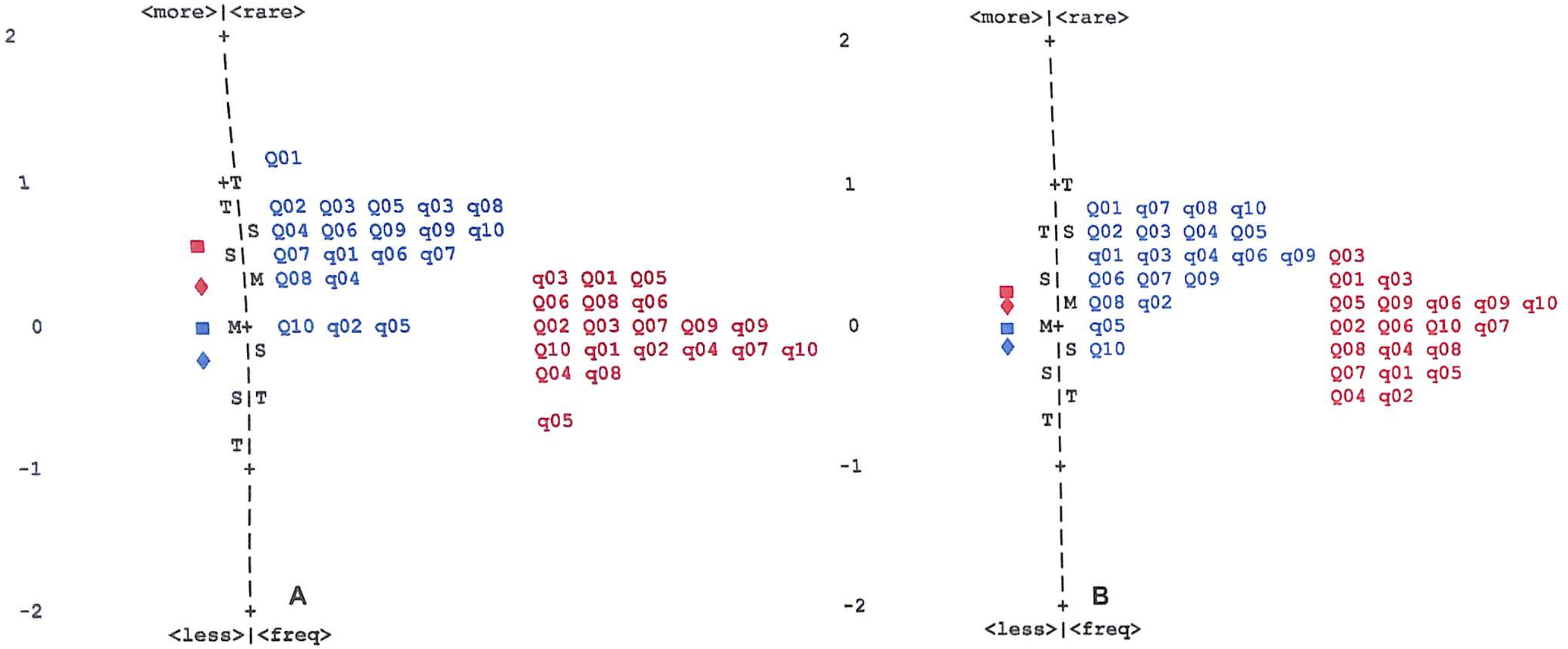


*Figure 4.5.* Wright map of CITI data showing pretest and posttest student ability and item difficulty

Item difficulties were derived from racked analysis. Mean abilities were derived from stacked analysis.
A = mereology-based instruction group; B = conventional instruction group.

**Legend:** 🟦 Mean of male students, pretest 🟥 Mean of male students, posttest
◆ Mean of female students, pretest ◆ Mean of female students, posttest

Items in blue color are pretest items. Items in red color are posttest items.

Figure 4.6 shows the topic-specific changes in item difficulty in both groups. The topic-specific changes were obtained by grouping items per topic and determining the mean item difficulty and standard deviation. There was notably a larger decrease in the mean item difficulty in biochemistry topics, organic chemistry topics and general inorganic chemistry topics in favor of the mereology-based instruction group. In addition, the range of item difficulty of biochemistry topics in the conventional instruction group was larger during posttest, indicating that the effects of conventional instruction to item difficulty is highly variable.

In order to show the details regarding the number of students who improved after the instruction, the categories of answers per item need to be compared (Table 4.2.). Compared to the conventional instruction group, the mereology-based instruction group had a higher percentage increase in level 3 explanations during posttest in all items except for four biochemistry topics (**Q04**, **q03**, **q05** and **q06**) and one organic chemistry topic (**Q06**). This implies that the decrease in the difficulty in items **Q04**, **Q06**, **q03**, **q05** and **q06** in the mereology-based intervention group are attributed to an increase in either level 1 or level 2 explanations. It can also be observed that in the conventional instruction group, the percentage of students utilizing level 3 explanations decreased in general inorganic chemistry topics (**Q08**, **Q09** and **Q10**) and one biochemistry topic (**Q07**).

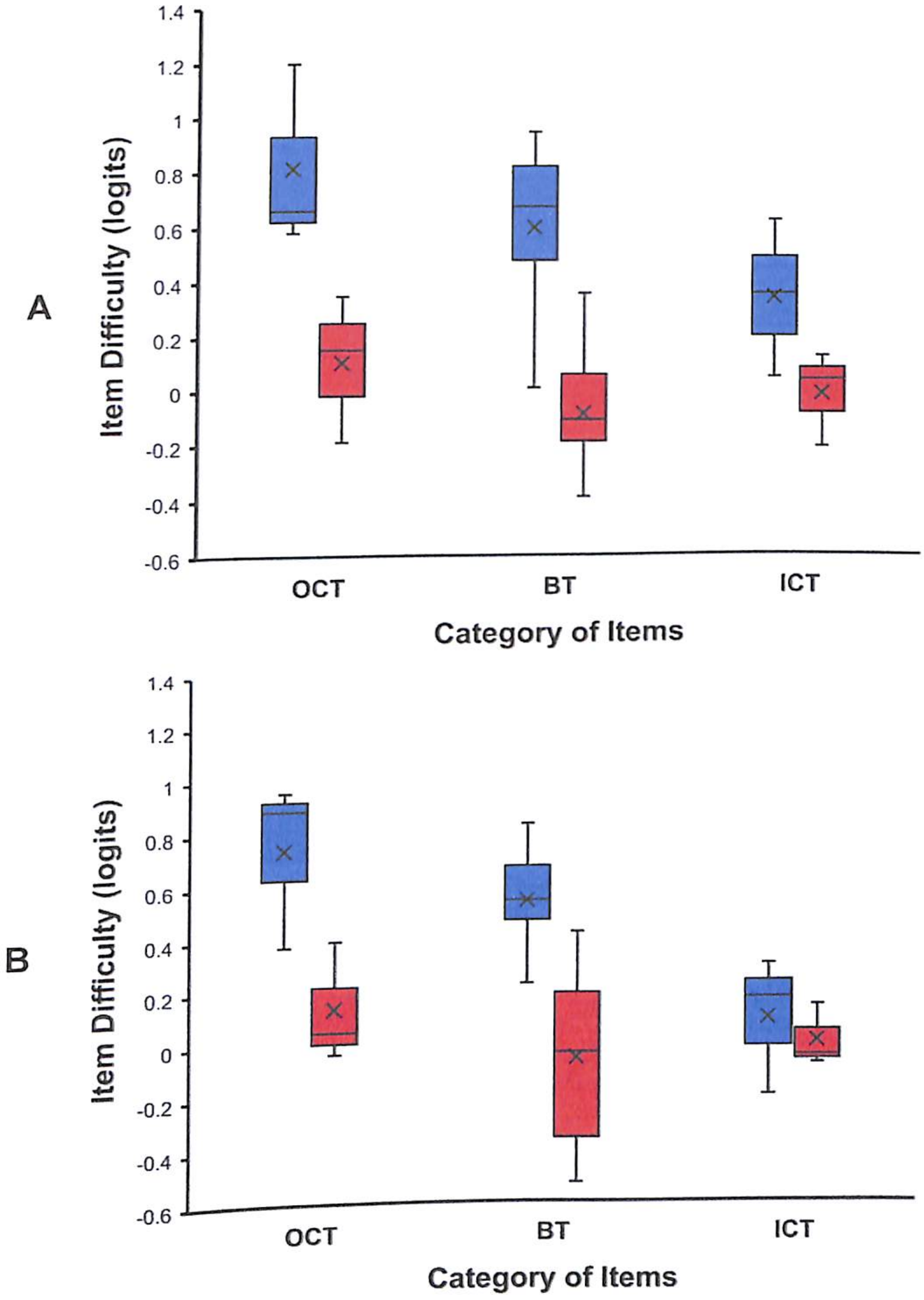


*Figure 4.6.* Changes in difficulty of CITI items based on category of topics
A = mereology-based instruction group; B = conventional instruction group; Blue box plots = pretest; red boxplots = posttest

4.2.

*tage of answers per level in chemical identity thinking instrument*

| m | Level | MBI Group |  |  | CI Group |  |  |
|---|---|---|---|---|---|---|---|
|  |  | Pretest | Posttest | Difference | Pretest | Posttest | Difference |
| 01 | 0 | 32.06 | 21.25 | -10.80 | 28.22 | 12.20 | -16.03 |
|  | 1 | 47.39 | 45.64 | -1.74 | 48.08 | 60.63 | 12.54 |
|  | 2 | 20.21 | 25.44 | 5.23 | 20.91 | 23.00 | 2.09 |
|  | 3 | 1.39 | 8.71 | 7.32 | 2.79 | 4.18 | 1.39 |
| 02 | 0 | 21.60 | 9.76 | -11.85 | 9.41 | 12.54 | 3.14 |
|  | 1 | 57.14 | 65.16 | 8.01 | 59.58 | 58.19 | -1.39 |
|  | 2 | 19.86 | 12.54 | -7.32 | 29.62 | 18.47 | -11.15 |
|  | 3 | 2.44 | 13.59 | 11.15 | 1.39 | 10.80 | 9.41 |
| 03 | 0 | 25.09 | 12.89 | -12.20 | 25.09 | 13.59 | -11.50 |
|  | 1 | 47.04 | 49.13 | 2.09 | 37.98 | 58.89 | 20.91 |
|  | 2 | 26.13 | 27.53 | 1.39 | 33.80 | 23.34 | -10.45 |
|  | 3 | 2.79 | 11.50 | 8.71 | 3.14 | 4.18 | 1.05 |
| 04 | 0 | 20.56 | 6.27 | -14.29 | 23.34 | 6.27 | -17.07 |
|  | 1 | 27.18 | 40.07 | 12.89 | 26.83 | 35.19 | 8.36 |
|  | 2 | 50.52 | 36.24 | -14.29 | 45.64 | 31.01 | -14.63 |
|  | 3 | 2.79 | 18.47 | 15.68 | 4.18 | 27.53 | 23.34 |
| 05 | 0 | 31.36 | 25.44 | -5.92 | 24.39 | 15.68 | -8.71 |
|  | 1 | 49.13 | 42.51 | -6.62 | 45.30 | 55.75 | 10.45 |
|  | 2 | 17.77 | 20.56 | 2.79 | 25.78 | 19.51 | -6.27 |
|  | 3 | 2.79 | 12.54 | 9.76 | 4.53 | 9.06 | 4.53 |
| 06 | 0 | 16.03 | 9.76 | -6.27 | 10.80 | 9.41 | -1.39 |
|  | 1 | 65.85 | 63.41 | -2.44 | 61.67 | 62.37 | 0.70 |
|  | 2 | 16.03 | 20.91 | 4.88 | 23.34 | 19.51 | -3.83 |
|  | 3 | 3.14 | 6.97 | 3.83 | 4.18 | 8.71 | 4.53 |
| 07 | 0 | 11.50 | 5.57 | -5.92 | 13.59 | 1.39 | -12.20 |
|  | 1 | 71.43 | 73.52 | 2.09 | 71.43 | 80.84 | 9.41 |
|  | 2 | 14.93 | 15.68 | 0.70 | 9.76 | 12.89 | 3.14 |
|  | 3 | 3.14 | 6.27 | 3.14 | 5.23 | 4.88 | -0.35 |
| 08 | 0 | 15.68 | 10.80 | -4.88 | 14.63 | 5.23 | -9.41 |
|  | 1 | 52.96 | 48.08 | -4.88 | 43.21 | 55.40 | 12.20 |
|  | 2 | 25.78 | 34.49 | 8.71 | 32.40 | 32.40 | 0.00 |
|  | 3 | 6.62 | 7.67 | 1.05 | 9.76 | 6.97 | -2.79 |
| 09 | 0 | 31.36 | 14.29 | -17.07 | 26.48 | 11.50 | -14.98 |
|  | 1 | 45.64 | 51.22 | 5.57 | 39.02 | 58.89 | 19.86 |
|  | 2 | 17.07 | 21.95 | 4.88 | 21.25 | 21.25 | 0.00 |
|  | 3 | 6.97 | 13.59 | 6.62 | 13.24 | 8.36 | -4.88 |
| 10 | 0 | 13.24 | 11.15 | -2.09 | 13.59 | 12.20 | -1.39 |
|  | 1 | 65.16 | 52.96 | -12.20 | 48.78 | 59.93 | 11.15 |
|  | 2 | 8.71 | 15.68 | 6.97 | 12.54 | 12.54 | 0.00 |
|  | 3 | 13.94 | 21.25 | 7.32 | 25.09 | 15.33 | -9.76 |

| Item | Level | MBI Group |  |  | CI Group |  |  |
|---|---|---|---|---|---|---|---|
|  |  | Pretest | Posttest | Difference | Pretest | Posttest | Difference |
| q01 | 0 | 24.39 | 14.98 | -9.41 | 27.18 | 8.36 | -18.82 |
|  | 1 | 41.11 | 44.60 | 3.48 | 31.36 | 51.22 | 19.86 |
|  | 2 | 28.22 | 16.03 | -12.20 | 34.15 | 18.47 | -15.68 |
|  | 3 | 7.32 | 25.44 | 18.12 | 7.32 | 21.95 | 14.63 |
| q02 | 0 | 21.25 | 16.38 | -4.88 | 22.65 | 9.76 | -12.89 |
|  | 1 | 33.45 | 31.01 | -2.44 | 40.42 | 26.48 | -13.94 |
|  | 2 | 26.48 | 26.48 | 0.00 | 23.34 | 32.06 | 8.71 |
|  | 3 | 19.86 | 27.18 | 7.32 | 13.59 | 31.71 | 18.12 |
| q03 | 0 | 3.48 | 7.67 | 4.18 | 3.14 | 5.57 | 2.44 |
|  | 1 | 48.78 | 52.26 | 3.48 | 41.11 | 58.89 | 17.77 |
|  | 2 | 48.43 | 38.33 | -10.10 | 55.05 | 33.45 | -21.60 |
|  | 3 | 0.35 | 2.79 | 2.44 | 0.70 | 2.09 | 1.39 |
| q04 | 0 | 27.18 | 11.85 | -15.33 | 26.83 | 13.24 | -13.59 |
|  | 1 | 43.90 | 52.26 | 8.36 | 50.87 | 41.11 | -9.76 |
|  | 2 | 18.82 | 18.47 | -0.35 | 14.29 | 22.65 | 8.36 |
|  | 3 | 11.15 | 18.47 | 7.32 | 8.01 | 23.00 | 14.98 |
| q05 | 0 | 6.27 | 3.14 | -3.14 | 9.41 | 8.01 | -1.39 |
|  | 1 | 50.17 | 25.09 | -25.09 | 41.81 | 32.75 | -9.06 |
|  | 2 | 38.33 | 52.61 | 14.29 | 41.11 | 36.93 | -4.18 |
|  | 3 | 6.27 | 20.21 | 13.94 | 7.67 | 22.30 | 14.63 |
| q06 | 0 | 29.97 | 24.39 | -5.57 | 25.78 | 24.39 | -1.39 |
|  | 1 | 41.81 | 41.81 | 0.00 | 36.93 | 43.90 | 6.97 |
|  | 2 | 19.51 | 14.63 | -4.88 | 31.71 | 15.68 | -16.03 |
|  | 3 | 9.76 | 20.21 | 10.45 | 5.57 | 16.03 | 10.45 |
| q07 | 0 | 22.30 | 9.41 | -12.89 | 25.09 | 9.76 | -15.33 |
|  | 1 | 57.84 | 56.10 | -1.74 | 57.14 | 63.41 | 6.27 |
|  | 2 | 15.33 | 18.12 | 2.79 | 15.68 | 15.33 | -0.35 |
|  | 3 | 5.57 | 17.42 | 11.85 | 2.09 | 11.50 | 9.41 |
| q08 | 0 | 28.22 | 12.20 | -16.03 | 18.82 | 10.45 | -8.36 |
|  | 1 | 58.54 | 52.61 | -5.92 | 63.07 | 53.66 | -9.41 |
|  | 2 | 11.50 | 7.67 | -3.83 | 16.03 | 18.82 | 2.79 |
|  | 3 | 2.79 | 28.57 | 25.78 | 2.09 | 17.07 | 14.98 |
| q09 | 0 | 21.25 | 13.24 | -8.01 | 18.82 | 13.59 | -5.23 |
|  | 1 | 52.61 | 43.90 | -8.71 | 55.05 | 51.92 | -3.14 |
|  | 2 | 23.00 | 32.40 | 9.41 | 20.56 | 26.48 | 5.92 |
|  | 3 | 4.18 | 11.50 | 7.32 | 5.57 | 8.01 | 2.44 |
| q10 | 0 | 24.74 | 8.71 | -16.03 | 23.69 | 16.03 | -7.67 |
|  | 1 | 44.25 | 37.63 | -6.62 | 45.30 | 39.72 | -5.57 |
|  | 2 | 28.57 | 41.46 | 12.89 | 27.18 | 33.80 | 6.62 |
|  | 3 | 3.48 | 13.24 | 9.76 | 2.79 | 10.45 | 7.67 |

refer to the meaning of level in chemical identity thinking instrument presented in Table 3.4 in Chapte3.

The item hierarchy in Figure 4.5. and changes in the number of students who had higher categories of explanations in Table 4.2. can be discussed in light of the types of explanations used by students in answering the items in the research instruments. Based on the analysis of data involving level 1 explanations, there are three common types of explanations – alternative conceptions, treating substances as molecules, and associating the terms with students' bias and preconceptions. These types of explanations can be observed among students in the mereology-based instruction group and conventional instruction group.

Most alternative conceptions of students during the posttest were related to an inaccurate conceptual understanding. The persistence of alternative conceptions in differentiating substances during posttest imply that students were focusing on surface features, not on the linking of macroscopic concepts to the sub-microscopic domains. Novice learners often focus on surface features while expert learners use their knowledge to see underlying principles in a problem situation (Kozma & Russell, 1997). It is evident that students still think that bulk samples and their molecular components are thought to share the same properties, while in fact, it is the interaction of the molecules which give rise to the properties of the bulk sample (Talanquer, 2007).

The treatment of substances as molecules is common among students in both types of instruction, but is more common among students in the conventional instruction group. This type of explanation involves the differentiation of molecular structures when differentiating substances, assuming that molecules are "representatives" of the substances being compared. These explanations were categorized as *objectivization* as the focus was the description of molecules, not substances. In item **Q01**, for example, ethanol is described based on molecular structure, but the situation requires differentiation of bulk samples (ethyl alcohol and rubbing alcohol). This type of explanation was common in several items related to biochemistry topics such as saccharides, nucleic acids, and lipids.

Below are examples of student responses utilizing molecular structures when differentiating substances.

Item **q08** (sucrose and lactose)

Student CI159, M, posttest explanation:
*"A Benedict's test may be performed by determining the reducing property of the sugars. Sucrose is not a reducing sugar since the anomeric carbon is not available as compared to the lactose which has a free anomeric carbon. The glycosidic bond of sucrose is α (1 →2) glycosidic bond while lactose has an α (1 →4) glycosidic bond, thus the free anomeric carbon in sucrose is locked (carbon 2) while lactose is not (carbon 2)."*

Student CI63, F, posttest explanation:
*"Based on their structure, sucrose is non-reducing and lactose is reducing. Look at the anomeric carbon and the arrangement of the OH and H."*

Student CI139, F, posttest explanation:
*"Lactose and sucrose would have the same formula but they are not structurally the same. Table sugar would consist of one hexagonal structure bonded to one pentose ring while lactose has two hexagonal structures bonded together."*

Item **q06** (nucleotide and dietary nucleotide)

Student MBI141, F, posttest explanation:
*"If the nucleotides base pairings of A-T and C-G of the DNA molecules is the same as that in the milk products contains dietary nucleotides. It is the same with the principle of RNA molecule which is single stranded and has a pairing of A-U and C-G through folding."*

Student CI44, M, posttest explanation:
*"Nucleotides are the monomers of DNA and ribonucleotides are for RNA. The television said that it is a "nucleotide." Therefore, it is DNA."*

Student MBI25, F, posttest explanation:
*"If the sequence of its resulting amino acids is similar,* then they are similar."

Student CI85, F, posttest explanation:
*"DNA and RNA can be differentiated from dietary nucleotide by determining the type of sugar component present. If it is deoxyribose, then it is DNA. If it is ribose, it is RNA."*

Item **Q05** (butter and margarine)

Student CI45, M, posttest explanation:
*"Butter and margarine are both saturated molecules and easily get stacked together. Butter and margarine also have same components and sources. But their type of fatty acid isn't the same. Margarine is from vegetable oil and butter is from a dairy milk."*

Student CI249, F, posttest explanation:
*"Butter is not solid at room temperature. Thus, it contains polyunsaturated fatty acids. Margarine is solid at room temperature. Therefore, it is a saturated fatty acid."*

For both groups, it was also common to associate health contexts when differentiating substances, based on the common understanding of a terminology, but these explanations were also more common among students in the conventional instruction group. For example, "*saturated fatty acid*" is automatically perceived as unhealthy while "*unsaturated fatty acid*" is viewed as healthy. Similarly, margarine is associated with the presence of "*trans*-fats" or "*chemical processing*", making students view margarine as unhealthy foodstuff. Here are sample responses from students.

Student CI1221, F, posttest explanation:
Fat comes from the unsaturated lipids of animal sources while oil comes from unsaturated lipids of plant source. Oils are healthier than fats because they remain liquid in room temperature. Fats may cause atherosclerosis too.

Student MBI69, F, posttest explanation:
From what I've learned in organic and organic chemistry last semester, margarine is different from butter. Margarine is healthier than butter because butter is more processed. So, butter leads to heart diseases.

Fats and fatty foods have long been linked to atherosclerosis formation and cardiovascular diseases. These were common during pretest and posttest for both groups, indicating that the type of instruction may not have completely removed the notion of associating health contexts when differentiating substances among health science students.

Chemical identity thinking is important in learning biochemistry and health concepts because some terms in chemistry are understood differently in the context of nutrition, pharmacology and diagnostic procedures. An example is the term "*chemical.*" In the context of chemistry, a chemical simply refers to a substance or compound. In the health sciences, the term may have negative implications to nutrition since it is commonly linked to terms such as "*preservatives*" or "*processed products.*" Similarly, the terms "*protein*" or "*fats*" are understood in biochemistry as molecules or classification of molecules with distinct set of properties, but in nutrition, the terms are simply referring to food macronutrients.

It was evident that using *compositionism* or *interactionism* over *objectivization* or *principlism* supports the changes in item difficulty and student abilities. According to Holme et al. (2015), a student who demonstrates conceptual understanding can "*reason core chemistry ideas using skill that go beyond mere rote memorization or algorithmic problem solving*" and "*translate across scales and representations.*" In *compositionism* or *interactionism* explanations, identifying a component and relating its attribute to the property of a mixture or a substance is evidence of reasoning beyond rote memorization and algorithmic problem solving, and is a clear link between the submicroscopic domain o the macroscopic domain in chemistry.

It has to be noted that students in both the mereology-based instruction group and the conventional instruction group were immersed in the same activities, and only ne approach is different. Instead of teaching students to use *part-whole* relationships in understanding biochemistry concepts, mereology-based instruction focused on evaluating *part-whole* relationships and stating their limitations in the context of biochemistry for health sciences. It is expected that students will use different approach of reasoning related to chemical identity to evaluate *part-whole* relationships. Also, the intervention does not involve "teaching the answers" to students, so the chemical explanations of students were the results of their own thought processes.

It is clear that students who utilized more *compositionism* or *interactionism* explanations during posttest exhibited higher conceptual understanding, and is demonstrated by conceptual change, as exhibited by a more sophisticated reasoning when differentiating chemical substances and mixtures. According to Duit and Treagust (2003), conceptual change is a "*restructuring of pre-instructional conceptual structures to allow understanding of intended knowledge.*" This framework is important when learning chemistry in the context of health because it allows application of prior chemistry knowledge to more dynamic chemical systems which are commonly discussed in biochemistry and health professional subjects.

The variations in chemical identity thinking are attributed to an inability to apply chemistry concepts to a new situation, such as differentiation of bulk samples. Using molecules to represent substances indicates a poor linking of chemistry concepts to describing chemical identity of substances. Loerstcher et al. (2014) has reported a similar observation where students in biochemistry think of individual molecules, not a "*population of molecules*" when discussing hemoglobin in blood. However, Banks et al. (2015) asserted that using the characteristics of chemical entities is a stepping stone towards more sophisticated chemical thinking.

Associating negative perceptions to terminologies may impede progression of conceptual understanding. In earlier studies, these strongly-held perceptions are classified as "*entrenched belief.*" Chinn and Brewer (1993) defined an "*entrenched belief*" as a belief which has a great deal of evidentiary support and participates in a broad range of explanations in various domains. The more entrenched a belief is, the more difficult and the harder it is to persuade an individual to change the belief.

It is likely that the existing bias may also contribute to the incorrect attribution of health effects to the terminologies. Connecting negative attributions to terms is similar to the report that the public generally has a negative attitude towards "*chemicals*" because they associate this to something "*synthetic*" and "*potentially toxic or harmful*" (Edwards et al., 2016). In the context of this study, a pre-existing negative conception about some terms may persist even after applying the intervention, as knowledge acquisition does not translate automatically to changes in perception or attitude. According to Todd et al. (2017), conceptual change does not necessarily happen if there is new knowledge or experience. Instead, students need to restructure their mental model, not only adding more details to the existing mental framework.

The persistence of alternative conceptions in differentiating substances during posttest imply that students were focusing on surface features. In chemistry education, novice learners often focus on surface features while expert learners use their knowledge to see underlying principles in a problem situation (Kozma & Russell, 1997). It is evident that students still think that bulk samples and their molecular components are thought to share the same properties, while in fact, it is the interaction of the molecules which give rise to the properties of the bulk sample (Talanquer, 2007).

Biochemistry concepts in the health sciences can be used to guide health decisions and understand disease processes. In addition, the integration of biochemistry concepts to health concepts clarifies how health interventions lead to optimal health (*intended knowledge*). Mereology-based instruction has promoted a greater use of *compositionism*- or *interactionism*-related chemical identity thinking compared to the use the same chemical identity thinking in the conventional instruction group. The ability to attribute a property to a component of a sample and to use emergent properties of a sample based on molecular interactions are essential in preparing students to link biochemistry concepts with health-related concepts

### Student Ability Differences in Critical Thinking in Chemistry

Over-all, students in the mereology-based instruction group had lower pretest mean student ability logit (M = -0.795, SD = 0.563) compared to the mean student ability logit in the conventional instruction group (M = -0.753. However, the posttest mean student ability logit in the mereology-based instruction group was higher (M = -0.423, SD = 0.534) than the mean student ability logits in the conventional instruction group (M = -0.550, SD = 0.508).

When grouped according to gender, male students in the mereology-based instruction group had the highest posttest student ability logit, followed by male students in the conventional instruction group (Table 4.3). The least posttest student ability logit was observed in female students in the conventional instruction group.

**Table 4.3.**

*Pretest and posttest student ability in critical thinking test in chemistry based on stacked Rasch analysis data*

| Group | Gender | Mean Student Ability Logit in CTTC | |
|---|---|---|---|
| | | Pretest | Posttest |
| Mereology-based instruction group | Male | $-0.617^{a}$ (0.584) | $-0.195^{a}$ (0.738) |
| | Female | $-0.912^{b}$ (0.424) | $-0.564^{b}$ (0.517) |
| Conventional instruction group | Male | $-0.624^{a}$ (0.415) | $-0.387^{b}$ (0.646) |
| | Female | $-0.858^{b}$ (0.430) | $-0.740^{c}$ (0.482) |

Means are expressed with SD. Means with different letters indicate statistically significant difference at $\alpha=0.05$. Mean pretest abilities significantly differ, $p=0.000$. All items fit the Rasch partial credit model

After controlling for ability logit in prior knowledge of chemistry concepts, there was a difference in the posttest mean ability logit of male and female students, $F_{(5, 537)}=12.990$, $p=0.000$, $\eta_p^2=0.064$. After controlling for ability logit in prior knowledge of visual representations, there was a significant difference in posttest mean ability logit of male and female students, $F_{(5,537)}=11.513$, $p=0.000$, $\eta_p^2=0.057$. Note that the effect sizes are small to medium, which explains that only 5.7% to 6.4% are accounted for by the type of instruction.

Pairwise comparisons revealed that male students in the mereology-based instruction group had statistically significantly higher ability compared to other students. Female students in the mereology-based instruction group and male students in the conventional instruction group do not have statistically significantly different mean ability. However, the mean posttest ability logit of female students in the conventional instruction group is statistically significantly lower than other students.

It is posited that in this study, gender differences in critical thinking may be attributed to the learning characteristics of students, not gender *per se*. While it is true that prior knowledge in chemistry and prior knowledge of visual representations play a role in answering items related to critical thinking, in this study, critical thinking is based on the immediate association of various concepts simultaneously since this is a characteristic required in answering chemistry items which are based on higher order thinking skills.

In the study of Gulacar et al. (2019), male students were revealed to organize information and build strong associations with chemistry-related concepts such as "*reaction*" and "*change*" in word association tests, while female students do not exhibit this ability. Selected items which exhibit high item difficulty in the PKCCT require multiple associations of chemistry concepts. The explanation provided by Gulacar et al. (2019) explains that the mental process required to answer these items may be related to the ability of male students to link multiple chemistry concepts at the same time. These results can also support the claim in this study that male students in the health sciences have higher prior knowledge of chemistry concepts. Gender differences in chemistry performance can also be explained by other factors. For example, male students exhibited higher self-efficacy and lower test anxiety in chemistry (Sunny et al., 2016).

Critical thinking has been defined differently by authors, and currently, there is no definite consensus on how to define critical thinking. In this study, the construct "*critical* *thinking in chemistry*" was operationalized based on a previous working definition of critical thinking. According to Garrat et al. (2000), a chemistry-specific critical thinking is based on "*how a professional chemist thinks,*" and the skills include *analyzing and evaluating arguments, making judgment, retrieving information* and *experimenting*. Similar to the study of Jacob (2004), argumentation was used in this study to measure critical thinking involving chemistry concepts.

The observed changes in critical thinking are directly influenced by the type of instruction used, and the types of activities performed by the students. The results agree with the results of studies which reported that using argumentation and other inquiry-based instructions increase critical thinking in chemistry (Gupta et al., 2014; Jacob, 2004), although the results on student ability in the critical thinking test in chemistry do not increase in all topics. In fact, this study affirms that learning is idiosyncratic (Hammer & Sikorski, 2015; Steedle & Shavelson, 2009) and is not captured easily by a single model of learning progression. Rasch analysis provided essential details to describe what changes occurred to student abilities and which specific topic caused these changes. When items fit the Rasch model, a change in item difficulty can be inferred as a change in the construct that is measured by a research instrument, which can be most likely attributed to an instruction effect (Pentecost & Barbera, 2013), although the change in mean item difficulty does not necessarily indicate an equal increase in the construct that is measured in the instrument.

It was clear that mereology-based instruction resulted to higher increase in student ability logits during posttest. *Part-whole* relationship, which is the main feature of mereology-based instruction, may have elicited critical thinking by providing opportunities to contrast two different types of thinking – attributing properties of "*parts*" and "*wholes*," and explaining the properties of the "*whole*" as attributes which are formed due to interaction of the "*parts*". Furthermore, the thinking process involved in mereology-based instruction requires ability to evaluate the *part-whole* relationships and recognize an incorrect reductionism of chemistry concepts.

Findlay and Thagard (2012) is promoting the utilization of a *part-whole* schema to study different levels of organization, ranging from atomic, biological and social levels. Apparently, part-whole relationship seems to reveal a structure-function relationship in their context of discussions, even at the sub-microscopic level. However, it is acknowledged there are also criticisms against a reductionist understanding of concepts in the context of *part-whole* relationship, especially with respect to the context related to living organisms. Van Regenmortel (2004) asserted that biological systems are complex and has emergent properties as mentioned on page 22. Similarly, this study asserts that part-whole relationship needs to be carefully used as when teaching concepts either in biology or chemistry.

Similar to the claim of Van Regenmortel (2004), chemistry concepts involve the recognition of emergent properties of chemical samples (Golden et al., 2017; Talanquer, 2007; Talanquer, 2018; Testa et al., 2014). Emergence relations can be observed at four levels – electrical, atomic, molecular and molar (Tümay, 2016), and the concept of emergence is based on the *part-whole* relation of lower-level entities. For example, the emergent molecular properties can be attributed to the property and interaction of atoms. Using the interaction of "*parts*" in a "*whole*" as conceptual basis for describing the properties of complex systems provide an opportunity for students to think and evaluate information critically.

In contrast, a *structure-property* relationship approach is based on mechanistic reasoning and establishing associations of chemistry-related evidence (Talanquer, 2018). *Structure-property* relationship is commonly used in chemistry and biology as frameworks for connecting conceptual understanding, constructing explanations, or predicting the effect of a change on a system (Kohn et al., 2018). Using a *structure-property* relationship to teach concepts in chemistry is also a common strategy in teaching chemistry (Croisant et al., 2019; Murphy, 2007; Stowe et al., 2019; Wnek, 2017). *Structure-property* relationship concepts are also taught along with *structure-activity* relationships particularly in medicinal chemistry (Carvalho et al., 2005; Frey, 2019; Ragno et al., 2020). Compared to *part-whole* relationship, a *structure-property* schema in the laboratory provides a specific point of reference (molecular structure) upon which students can build explanations on and then to associate them to properties or functions.

Based on the learning progression for critical thinking in chemistry, the mean student ability logits and standard deviations indicate that the pretest ability of students in both mereology-based instruction and conventional instruction is diverse. This suggests that careful analysis should be done to determine the progression of students in the levels of critical thinking in chemistry. This also justifies the need to investigate changes in item difficulties for both groups, which are discussed comprehensively in the succeeding sections.

Figure 4.7 shows the changes in the item difficulty in critical thinking test in chemistry. In the mereology-based instruction group, three general inorganic chemistry (GIC) items (**Q05, Q13, Q14**), four general organic chemistry (GOC) items (**Q01, Q04, Q07, Q15**), and seven laboratory concept (LC) items (**Q06, Q08, Q09, Q10, Q11, Q15** and **Q17**) decreased in item difficulty during posttest. Please refer to Appendix 3.14 for the details of critical thinking test in chemistry.

In the conventional instruction group, eleven items decreased in item difficulty – two GIC topics (**Q05, Q13**), three GOC topics (items **Q02, Q07 and Q15**), and six items related to laboratory skills (items **Q06, Q08, Q09, Q10, Q11** and **Q17**). In both groups, most items which decreased in difficulties during posttest were related to laboratory concepts such as principles of color tests, cleaning of glassware and laboratory procedures. This is expected since the bulk of activities in both groups were related to laboratory classes.

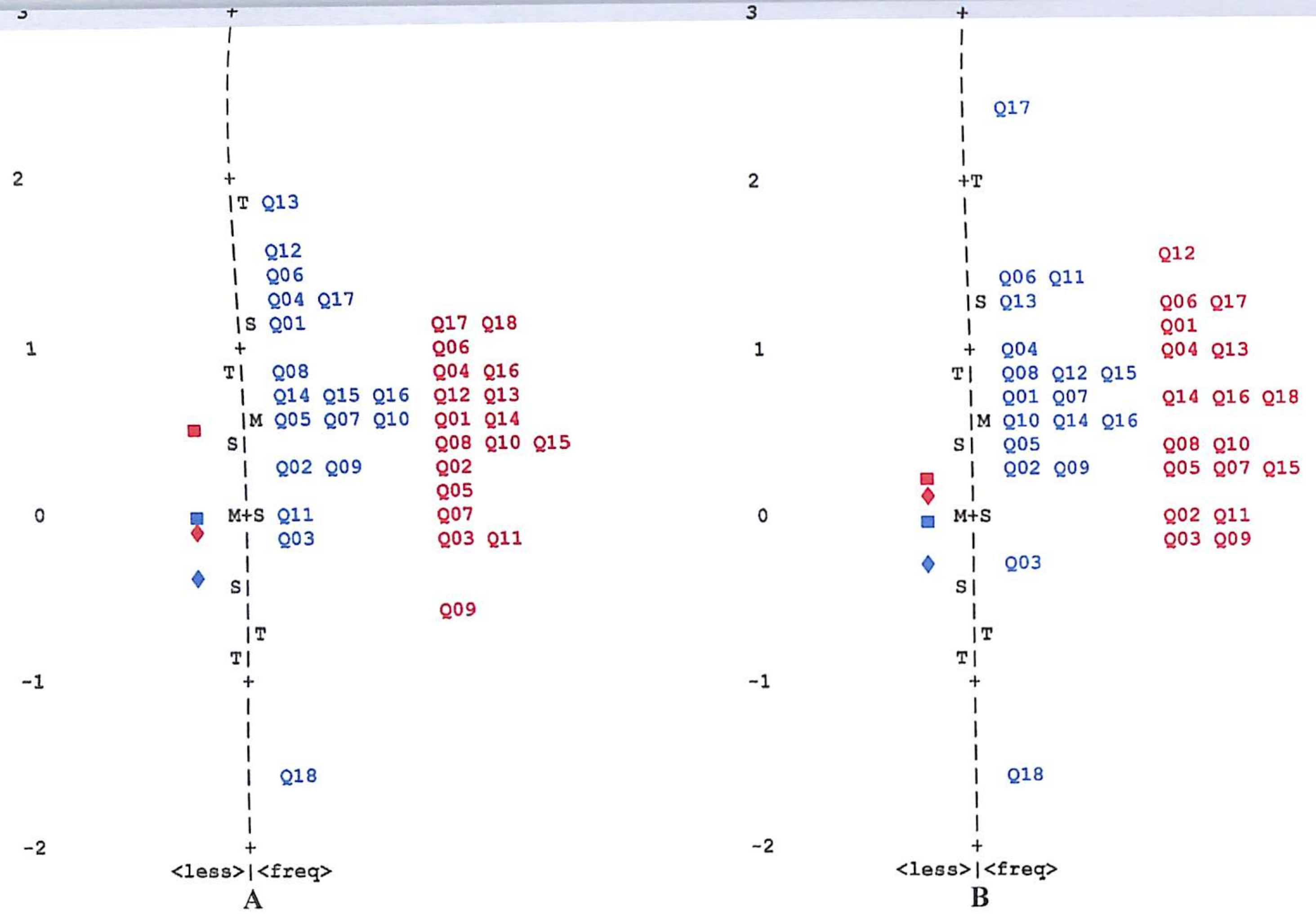


*Figure 4.7*. Wright map of CTTC data showing pretest and posttest student ability and item difficulty
Item difficulties were derived from racked analysis. Mean abilities were derived from stacked analysis. A=mereology-based instruction group; B=conventional instruction group

**Legend:**
- 🟦 Mean of male students, pretest
- 🟥 Mean of male students, posttest
- ◆ Mean of female students, pretest
- ◆ Mean of female students, posttest

Items in blue color are pretest items. Items in red color are posttest items.

In addition, Figure 4.8 shows that the decrease in item difficulty was highest in general organic chemistry (**GOC**) topics (N=5, M = 0.44, SD = 0.46), followed by laboratory concept (**LC**) topics (N=8, M = 0.35, SD = 0.29) and general inorganic chemistry (**GIC**) concepts (N=5, M = 0.28, SD = 0.47). For the conventional instruction group, the decrease in item difficulty involving laboratory concepts was higher (N=8, M = 0.43, SD = 0.69) compared to the mereology-based instruction group. There was also a very small decrease in the mean item difficulty of **GIC** topics (N=5, M = 0.02, SD = 0.21) and an increase in difficulty of **GOC** topics (N=5, M = -0.35, SD = 1.16). The increase in item difficulty of item **Q18** contributed greatly to the increase in the mean item difficulty of **GOC** topics in the conventional instruction group.

Further analysis in Table 4.4 reveals that sixteen items had less than 8% increase in level 3 answers for both mereology-based instruction group and conventional instruction group. In item **Q09**, level 3 answers increased by 34.14% in the mereology-based instruction group while in the conventional instruction group, level 3 answers increased by 22.65%. In item **Q11**, category 3 answers in the mereology-based instruction group increased by 17.24% while in the conventional instruction group, level 3 answers increased by 21.60%. Most answers in sixteen items were also classified as level 1 for both groups during pretest and posttest. In one item **Q03**, most answers were classified as level 3 during pretest and posttest for both groups.

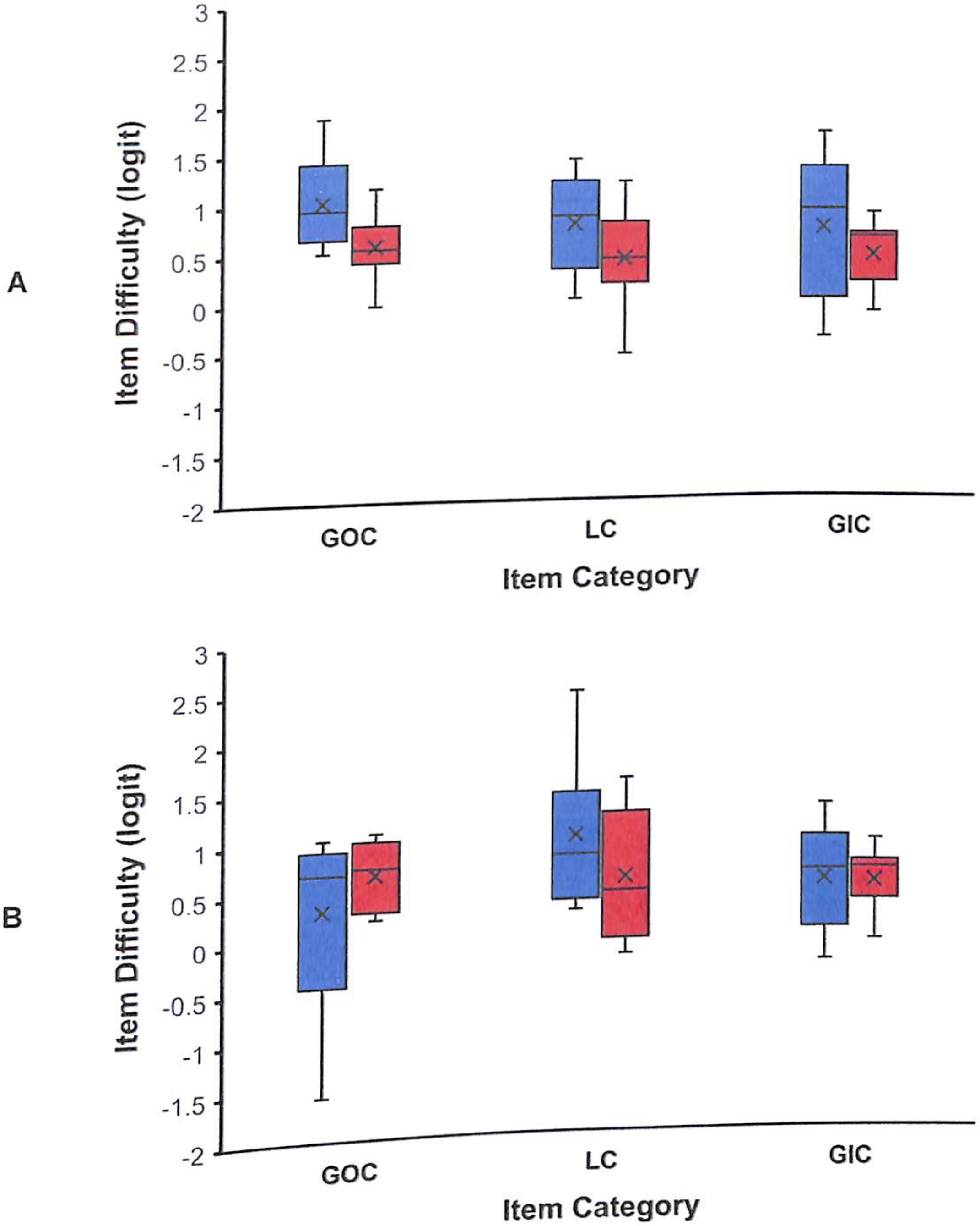


*Figure 4.8.* Changes in difficulty of CTTC items based on category of topics
A = mereology-based instruction group; B = conventional instruction group. Blue box plots = pretest; red boxplots = posttest

4.4.

*tage of responses per category in critical thinking test in chemistry*

| Level | MBI Group |  |  | CI Group |  |  |
|---|---|---|---|---|---|---|
|  | Pretest | Posttest | Difference | Pretest | Posttest | Difference |
| 0 | 37.93 | 23.79 | -14.14 | 29.27 | 33.80 | 4.53 |
| 1 | 44.14 | 50.69 | 6.55 | 50.17 | 58.79 | 6.62 |
| 2 | 15.86 | 19.66 | 3.79 | 15.68 | 7.67 | -8.01 |
| 3 | 2.07 | 5.86 | 3.79 | 4.88 | 1.74 | -3.14 |
| 0 | 10.34 | 20.69 | 10.34 | 14.98 | 12.54 | -2.44 |
| 1 | 70.00 | 40.69 | -29.31 | 65.16 | 56.79 | -8.36 |
| 2 | 13.45 | 28.28 | 14.83 | 11.50 | 16.03 | 4.53 |
| 3 | 6.21 | 10.34 | 4.14 | 8.36 | 14.63 | 6.27 |
| 0 | 26.90 | 27.59 | 0.69 | 21.95 | 24.04 | 2.09 |
| 1 | 25.17 | 25.52 | 0.34 | 21.60 | 28.57 | 6.97 |
| 2 | 4.48 | 9.31 | 4.83 | 10.45 | 17.07 | 6.62 |
| 3 | 43.45 | 37.59 | -5.86 | 45.99 | 30.31 | -15.68 |
| 0 | 62.41 | 52.41 | -10.00 | 51.57 | 45.99 | -5.57 |
| 1 | 30.69 | 32.76 | 2.07 | 39.37 | 42.88 | 3.48 |
| 2 | 4.83 | 7.24 | 2.41 | 5.23 | 8.01 | 2.79 |
| 3 | 2.07 | 7.59 | 5.52 | 3.83 | 3.14 | -0.70 |
| 0 | 23.79 | 15.52 | -8.28 | 19.16 | 19.16 | 0.00 |
| 1 | 48.62 | 47.93 | -0.69 | 39.72 | 44.95 | 5.23 |
| 2 | 21.72 | 26.90 | 5.17 | 34.15 | 27.87 | -6.27 |
| 3 | 5.86 | 9.66 | 3.79 | 6.97 | 8.01 | 1.05 |
| 0 | 30.69 | 28.62 | -2.07 | 34.49 | 35.19 | 0.70 |
| 1 | 65.86 | 64.14 | -1.72 | 62.02 | 53.66 | -8.36 |
| 2 | 2.76 | 4.83 | 2.07 | 2.79 | 10.10 | 7.32 |
| 3 | 0.69 | 2.41 | 1.72 | 0.70 | 1.05 | 0.35 |
| 0 | 18.62 | 11.72 | -6.90 | 21.60 | 11.50 | -10.10 |
| 1 | 63.79 | 40.34 | -23.45 | 63.07 | 66.20 | 3.14 |
| 2 | 12.41 | 35.52 | 23.10 | 11.50 | 17.07 | 5.57 |
| 3 | 5.17 | 12.41 | 7.24 | 3.83 | 5.23 | 1.30 |
| 0 | 36.90 | 31.72 | -5.17 | 34.84 | 34.15 | -0.70 |
| 1 | 56.21 | 44.14 | -12.07 | 55.40 | 42.51 | -12.89 |
| 2 | 2.76 | 13.10 | 10.34 | 5.57 | 11.50 | 5.92 |
| 3 | 4.14 | 11.03 | 6.90 | 4.18 | 11.85 | 7.67 |
| 0 | 13.79 | 10.00 | -3.79 | 11.50 | 16.72 | 5.23 |
| 1 | 43.10 | 23.79 | -19.31 | 45.99 | 24.39 | -21.60 |
| 2 | 37.59 | 28.55 | -11.03 | 37.63 | 31.36 | -6.27 |
| 3 | 5.52 | 39.66 | 34.14 | 4.88 | 27.53 | 22.65 |

| Item | Level | MBI Group |  |  | CI Group |  |  |
|---|---|---|---|---|---|---|---|
|  |  | Pretest | Posttest | Difference | Pretest | Posttest | Difference |
| Q10 | 0 | 28.97 | 30.00 | 1.03 | 32.06 | 36.93 | 4.88 |
|  | 1 | 34.48 | 33.10 | -1.38 | 35.54 | 38.33 | 2.79 |
|  | 2 | 30.34 | 27.24 | -3.10 | 25.44 | 14.29 | -11.15 |
|  | 3 | 6.21 | 9.66 | 3.45 | 6.97 | 10.45 | 3.48 |
| Q11 | 0 | 26.90 | 14.14 | -12.76 | 32.40 | 19.51 | -12.89 |
|  | 1 | 46.21 | 33.45 | -12.76 | 44.95 | 33.10 | -11.85 |
|  | 2 | 26.90 | 35.17 | 8.28 | 21.95 | 25.09 | 3.14 |
|  | 3 | 0.00 | 17.24 | 17.24 | 0.70 | 22.30 | 21.60 |
| Q12 | 0 | 32.07 | 25.17 | -6.90 | 26.13 | 28.22 | 2.09 |
|  | 1 | 66.55 | 59.31 | -7.24 | 68.29 | 63.07 | -5.23 |
|  | 2 | 1.38 | 11.72 | 10.34 | 5.57 | 8.36 | 2.79 |
|  | 3 | 0.00 | 3.79 | 3.79 | 0.00 | 0.35 | 0.35 |
| Q13 | 0 | 52.41 | 42.76 | -9.66 | 55.40 | 51.22 | -4.18 |
|  | 1 | 43.45 | 35.86 | -7.59 | 38.33 | 35.89 | -2.44 |
|  | 2 | 3.79 | 13.45 | 9.66 | 4.18 | 8.36 | 4.18 |
|  | 3 | 0.34 | 7.93 | 7.59 | 2.09 | 4.53 | 2.44 |
| Q14 | 0 | 33.45 | 26.90 | -6.55 | 29.97 | 29.62 | -0.35 |
|  | 1 | 56.55 | 57.24 | 0.69 | 60.63 | 55.75 | -4.88 |
|  | 2 | 3.45 | 10.34 | 6.90 | 3.14 | 10.10 | 6.97 |
|  | 3 | 6.55 | 5.52 | -1.03 | 6.27 | 4.53 | -1.74 |
| Q15 | 0 | 25.86 | 22.41 | -3.45 | 24.04 | 17.77 | -6.27 |
|  | 1 | 63.45 | 60.69 | -2.76 | 69.69 | 65.51 | -4.18 |
|  | 2 | 6.21 | 8.62 | 2.41 | 3.14 | 6.27 | 3.14 |
|  | 3 | 4.48 | 8.28 | 3.79 | 3.14 | 10.45 | 7.32 |
| Q16 | 0 | 51.38 | 44.48 | -6.90 | 44.95 | 43.21 | -1.74 |
|  | 1 | 24.83 | 28.97 | 4.14 | 26.83 | 36.24 | 9.41 |
|  | 2 | 13.55 | 22.07 | 5.52 | 18.82 | 12.54 | -6.27 |
|  | 3 | 7.24 | 4.48 | -2.76 | 9.41 | 8.01 | -1.39 |
| Q17 | 0 | 41.72 | 37.93 | -3.79 | 42.51 | 45.99 | 3.48 |
|  | 1 | 56.55 | 55.52 | -1.03 | 57.14 | 42.16 | -14.98 |
|  | 2 | 0.00 | 4.83 | 4.83 | 0.35 | 10.10 | 9.76 |
|  | 3 | 1.72 | 1.72 | 0.00 | 0.00 | 1.74 | 1.74 |
| Q18 | 0 | 18.62 | 21.72 | 3.10 | 18.47 | 16.72 | -1.74 |
|  | 1 | 81.38 | 72.41 | -8.97 | 81.53 | 79.44 | -2.09 |
|  | 2 | 0.00 | 4.83 | 4.83 | 0.00 | 3.83 | 3.83 |
|  | 3 | 0.00 | 1.03 | 1.03 | 0.00 | 0.00 | 0.00 |

efer to Table 3.5 in Chapter 3 to review the meaning of each level in critical thinking in chemistry test.

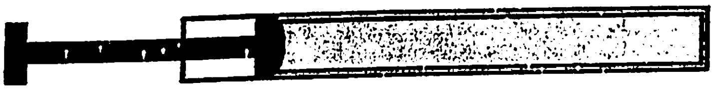
Details of changes in specific items are compared to provide a clear picture on what type of changes happened in the two groups. A higher mean posttest ability and decrease in item difficulty during posttest suggest an increase in critical thinking in chemistry, but the interpretation should be carefully made as difficulty logits had varied changes. Based on Figure 4.7, item **Q03, Q16** and **Q18** increased in item difficulty. In the mereology-based instruction group, item **Q02** became more difficult. For the conventional instruction group, items **Q01**, **Q04 Q12** and **Q14** became more difficult. Based on the analysis of changes in these items (Table 4.4.), lower categories such as level 0 and level 1 increased in these items, while level 2 and level 3 answers decreased. To review, explanations in level 0 and 1 may be due to alternative conceptions or unrelated answers.

Based on the results in item difficulty changes, items which increased in item difficulty were related to *stoichiometry*, *chemical equilibrium* and *intermolecular forces of attraction*. It is well-documented that misconceptions are common about stoichiometry concepts (Fach et al., 2007; Huddle and Pillay, 1996), chemical equilibrium (Huddle and Pillay, 1996; Quilez-Pardo & Solaz-Portoles, 1995), and intermolecular forces of attraction (Cooper et al.,2015; Widarti et al., 2019), and this study support the foregoing findings. It is also observed that in the conventional instruction group, concepts related to acidity, alkalinity, polarity and analysis of mixtures became more difficult. These concepts have already been discussed during general inorganic and organic chemistry, prior to their biochemistry subject.

In the *stoichiometry* topic (item **Q03**), the conventional instruction group has a greater percentage decrease in *category 3* answers, and greater increase in level 1 and level 2 answers. Some explanations present the same concept, but the rigor of explanation was visibly less during posttest. The results agree with the observation of Weinrich and Talanquer (2016) that a more advanced knowledge may not always lead to sophisticated chemistry reasoning, but became direct to the point.

In the conventional instruction group, it was observed that in the explanations related to *chemical equilibrium in a closed system* (item **Q16**), students thought that increasing the pressure inside a plunger (through a forward movement), also promotes a forward reaction. Please refer to the question below on item **Q16**.

A chemical reaction is occurring in a sealed vessel. The vessel has a plunger which can be moved to increase or decrease the pressure inside the vessel.



The reaction inside the vessel is shown below.

$$NH_4Cl_{(s)} \rightleftharpoons NH_{3(g)} + HCl_{(g)}$$

If the plunger is pushed forward, it is expected that there will be more formation of $NH_4Cl_{(s)}$.

○ **Valid** ○ **Invalid**

The finding of this study supports the report of Taskin and Bernholt (2014) that students often make erroneous connections in different domains of chemistry. In this study, students misinterpret that the forward reaction of the plunger in the illustration refers to the forward reaction of the chemical equation. In item **Q16** (*chemical equilibrium in a closed system*), students in both groups used explanations are either neutral, or copied directly from the situation provided. However, some students, exhibit misconceptions.

Some representative explanations are shown below.

Student MBI03, M, posttest explanation
*"The chemical reaction equation shows a decomposition reaction, meaning as the reaction vessel is decreased then the reaction towards the forward direction would be favored. So $NH_3(g)$ and $HCl(g)$ which are the products should form more."*

Student CI03, M, posttest explanation
*"If it will be pushed forward, it is expected that there will be a formation of $NH_{3(g)}$ + $HCl_{(g)}$ because these are the products in the forward reaction"*

An intervention does not automatically lead to deep conceptual learning (Jones et al., 2014), and the same can be said for mereology-based instruction. It is also acknowledged that providing activities may not always promote reflection of data after performing laboratory activities (Schroeder et al., 2017). When concepts become difficult, health science students often use surface learning for the sake of passing the subject (Jones et al., 2014; Minasian-Batmanian et al., 2005). In the Philippines, health science programs are quota courses and policies in student retention are based on the students' grades. It is possible that students learned concepts for the sake of passing their biochemistry subject, since this is a prerequisite subject for all professional subjects in the program.

For group-specific increase in item difficulties, there are more items which increased in item difficulties in the conventional instruction group. These are items **Q01** (-OH *group misconception,* **GOC** topic), **Q14** (*acidity,* **GIC** topic), **Q04** (*molecular geometry and polarity,* **GOC** topic), **Q12** (*mixture analysis,* **GOC** topic). In item **Q01**, the most common misconception is related to the notion that a hydroxyl group (-OH) is the same as hydroxide ions ($OH^-$). The results imply that concepts which involve submicroscopic representations and pH equilibrium may be more difficult for students to learn, thereby requiring more conceptual reinforcement by providing more examples, or simultaneous presentation of multiple representations and actual laboratory data to strengthen the critical thinking skills of students.

In item **Q14**, the increase in item difficulty was attributed to an increase in *category 0* answers (wrong claim and wrong evidence). Also, it was observed that most answers during posttest were classified as level 1 (correct claim, wrong evidence), because the evidence are unjustified or incorrect explanations. Some answers were related to the notion that acetic acid is a base since it has OH group.

The findings in this study about misconceptions related to acids and bases are similar to the findings of Mubarokah et al. (2018). Based on their findings, students from Indonesia and Thailand perceive that any molecule with OH are classified as bases. In addition, students only focus on the idea that H atoms cause acidity while the presence of OH indicates alkalinity. In this study, students also associate acidity and alkalinity with the presence of H or OH in the structure.

In item **Q04**, most answers in the conventional instruction group during posttest were classified as *category 0* (45.99%, post), indicating a wrong claim and inaccurate, unrelated or unjustified evidence. Answers which were classified as *category 1* and *category 2* also increased by 3.48% and 2.79%, respectively. The results in this study were related to the misconception which was described by Erman (2016), that "*all bonds in polar molecules are polarized and all bonds in nonpolar molecules are not polarized*" which was identified by Talanquer (2014) as a one-reason decision making, a type of heuristic reasoning.

In addition, Uyulgan and Azzuku (2016) reported that freshman university students understand the concept of bond polarity, but fail to relate it to molecular polarity. A correct understanding of molecular geometry, bond polarity and molecular polarity is used to describe intermolecular interactions in several biomolecules. Hence, this concept needs to be carefully addressed when teaching health science students.

In item **Q12**, most answers of students in the conventional instruction group are classified as level 1. During posttest, answers which were classified as level 0 (2.09%, post) or level 2 (2.79%, post) also increased in percentage. This means that most students still had inaccurate or unjustified explanations during posttest. Based on these explanations, students in the conventional instruction lacked critical analysis of the data presented in the situation.

Jacob (2004) previously found in a study that during argumentation activities, third year college students do not know how to relate observations, theories and conclusions in a systematic manner. A similar observation is observed in this study, as students do not justify how proteins cause acidity of a mixture. Furthermore, it is observed that students make incorrect assumptions about amino acids being acidic and contributory to the acidity of proteins. This type of thinking, known as heuristic thinking, is commonly used by students under conditions of limited knowledge, time, and motivation (Talanquer, 2014).

In the mereology-based instruction group, item **Q02** (*intermolecular force of attraction,* **GOC** topic) also became slightly more difficult by 0.07 logit. Based on the changes during posttest, level 0 answers increased by 10.34%, implying that students had a wrong claim and wrong evidence. A common concept in the submicroscopic domain is the notion that molecules dissociate into atoms when a sample is heated. Similar to the findings of Kirbulut and Keeth (2011), alternative conceptions about evaporation, boiling and condensation are common in the submicroscopic domain as revealed in the students' explanations in this study. Some students who identified carbon dioxide as the cause of the balloon inflation may have associated their laboratory activity involving fermentation of sucrose by yeast cells, which is part of the laboratory activities in both types of instruction. The laboratory set-up also involved the inflation of balloon, which students might have associated with in their answers in the posttest. Talanquer (2014) has described this as a "*recognition heuristic.*"

The results in critical thinking in chemistry using Rasch partial credit model has generated substantial information on how intervention influence learning in health sciences program using the changes in student ability and item difficulty. It is clear that critical thinking tasks in chemistry are generally approached by health science students using heuristics, and more sophisticated chemistry reasoning was attributed to increased conceptual understanding. The effects to critical thinking in chemistry may not be attributed solely to the type of instruction alone, but also to the impact of student characteristics, teacher-related factors, curriculum, and context.

**Student Ability Differences in Chemistry-based Health Literacy**

In general, students in the conventional instruction group had higher pretest mean student ability logit (M = -0.628, SD = 0.480) compared to students in the mereology-based instruction group (M = -0.641, SD = 0.497). During posttest, the mean student ability of students in the mereology-based instruction group was higher (M = 0.049, SD = 0.578) compared to students in the conventional instruction group (M = -0.346, SD = 0.472).

Table 4.5 shows that male students in the mereology-based instruction group had the highest mean pretest ability while female students in the same group had the lowest mean pretest ability. After posttest, male students in the mereology-based instruction group had the highest mean posttest ability, while female students in the conventional instruction group had the lowest posttest mean ability. Over-all, male students had higher mean posttest abilities compared to female students.

**Table 4.5.**

*Pretest and posttest student ability in chemistry-based health literacy*

| Group | Gender | Mean Student Ability Logit | |
|---|---|---|---|
| | | Pretest | Posttest |
| **Mereology-based instruction group** | Male | -0.507 (0.529) | $0.359^a$(0.842) |
| | Female | -0.633 (0.564) | $0.004^b$ (0.605) |
| **Conventional instruction group** | Male | -0.538 (0.547) | $-0.347^c$ (0.551) |
| | Female | -0.668 (0.557) | $-0.418^c$ (0.532) |

Means are expressed with SD. Means with different letters indicate statistically significant difference at $\alpha=0.05$. Mean pretest abilities do not significantly differ, $p=0.160$. All items fit the Rasch partial credit model.

After controlling for ability logit in prior knowledge of chemistry concepts, there was a significant effect of type of intervention to the posttest mean ability logit of male and female students, $F_{(5, 537)}=33.052$, $p=0.000$, partial $\eta_p^2=0.148$. After controlling for ability logit in prior knowledge of visual representations, there was a significant effect of type of intervention to the posttest mean ability logit of male and female students, $F_{(5,537)}=32.193$, $p=0.000$, $\eta_p^2=0.144$. After controlling for the covariates, the variance among the groups was accounted for by the type of instruction by 14.4% to 14.8%.

Pairwise comparisons revealed that male students in the mereology-based instruction group had statistically significantly higher posttest mean ability scores compared to all students. The mean posttest ability logit of female students in the mereology-based instruction group was statistically significantly higher than the mean posttest ability of male and female students in the conventional instruction group. Male and female students in the conventional group had no statistically significant differences in posttest mean ability. The results indicate that mereology-based instruction presents an advantage in improving the reasoning skills involved in linking chemistry concepts to health concepts.

The observed gender differences may be attributed to the learning characteristics of male and female students. The items in chemistry-based health literacy test requires the ability to link chemistry concepts to health literacy concepts, which require careful analysis of available chemical and health data in the given situation, and use them to infer correct health decisions or conclusions. The accuracy and sophistication of answers, therefore, involves critical analysis of both chemistry concepts and health-related concepts while integrating other subjects in health sciences such as anatomy and physiology, pharmacology, and diagnostic procedures.

It has been explained previously that male and female students differ in their ability to associate chemistry terms immediately (Gulacar, 2019). This stark difference can also be rationalized to be true when linking chemistry concepts to health concepts. To the author's knowledge, this is a first attempt to investigate how students link chemistry and health concepts in order to choose a correct health decision. While reports on the differences between male and female students in chemistry are inconsistent, it is generally recognized that chemistry achievement is influenced by the interaction of cognitive and non-cognitive factors.

The utilization of *part-whole* relationship is asserted to be the major contributor to the ability to link chemistry concepts to health concepts. It has long been recognized that chemistry plays a role in achieving health outcomes, not only through the development of safe and effective medicine for communicable and non-communicable diseases, but through the diagnosis of diseases as well (Matlin, 2017). Chemistry has been utilized in the understanding of molecular pathways of diseases, epigenetics, methods for disease diagnosis, drug discovery and drug development (Chemistry for Better Health, 2011).

Efforts have been done to link chemistry concepts to health concepts in other studies (Armstrong & Foe, 2020; Goeden et al., 2015), but their approach was to discuss chemistry content which are embedded in health contexts. In contrast, this study focused on a *thinking approach* (*part-whole* relationship or *mereology*) in biochemistry to target health literacy. Health is a socio-scientific issue, and this study used an approach in learning chemistry concepts and transfer this thinking process to make decisions in the context of health literacy. Similarly, Eggert et al. (2016), which focused on using a teaching strategy to enhance socio-scientific reasoning in climate change, while Owens et al. (2020) focused on improving content knowledge. In this study, the focus was to use *part-whole* relationship within chemistry context to address health literacy.

This discussion first justifies why chemistry-based health literacy is also addressed in this study in the context of biochemistry instruction in health programs in the Philippines. Second, the features of mereology-based instruction and conventional instruction are compared and linked to the changes in posttest student abilities and item difficulties. Lastly, the similarities and differences in the approach of explanations in both groups were discussed.

The results in chemistry-based health literacy construct supports the notion that indeed, learning is idiosyncratic (Hammer & Sikorski, 2015; Steedle & Shavelson, 2009), and the learning progression in chemistry-based health literacy cannot be attributed to an increased conceptual of chemistry concepts, but a constant modification of reasoning based on a selective integration of chemistry concepts, physiology concepts, preconceptions and sociocultural factors. Male students, in particular, gained the highest posttest ability in the mereology-based instruction group compared to female students. Again, this could be related to a higher ability of male students to build strong connections to prior knowledge and new concepts (Gulacar, 2019). This observation resonates with the report that male students prefer rational evaluation and logic while female students seek to find relevance to the concept being taught (Wehrwein et al., 2007).

Similarly, in the study of Eggert et al. (2016) about climate change and the use of computer-based concept mapping scaffolds, the skills exhibited by students during posttest were related to the characteristics of the intervention (i.e., increased concept in intervention led to higher conceptual map; increased argumentative relations resulted to solutions). Mereology-based instruction requires students to link the ontological nature of mereology in chemistry and look for relevant concepts to support the claim. These activities require more cognitive tasks for students using conventional resources such as books, published journals, and videos, which do not explicitly discuss *part-whole* relationships. In contrast, *structure-property* relationships are common in biochemistry textbooks and journals.

Based on the results in Table 4.5., the mean student ability logits and standard deviations indicate that the pretest abilities of students in both mereology-based instruction and conventional instruction are diverse. This suggests that careful analysis should be done to determine the progression of students in the levels of chemistry-based health literacy. This also justifies the need to investigate changes in item difficulties, which are discussed in the succeeding sections.

Based on Figure 4.9, the most difficult items in the mereology-based instruction group during pretest were items **N3** (*compound R in fruits*) and **P2** (*fungal* *infection and antibacterial*), while the easiest items were items **N2** (*citrus-flavored noodle product*) and **P1** (*antibacterial drug and deactivation*). During posttest, the easiest items were items **NP2** (*vasodilatation in rats*) and **N3** (*compound R in fruits*) while the most difficult items were **N2** (*citrus-flavored noodle product*) and **NP1** (*milk product and heat-sensitive compound*). All items decreased in item difficulty. Male students in the mereology-based instruction group also outperformed female students in items **NP2** (*vasodilatation in rats*), **N3** (*compound R in fruits*), **P2** (*fungal infection and antibacterial*) and **NP3** (*product containing oxidizable compound*). Please refer to Appendix Q for the details of each item.

In the conventional instruction group, the most difficult items were items **N3** (*compound R in fruits*) and **P2** (*fungal infection and antibacterial*), while the easiest item was item **N2** (*citrus-flavored noodle product*). During posttest, the most difficult items were still items **N3** (*compound R in fruits*) and **P2** (*fungal infection and antibacterial*), while the easiest item was still item **N2** (*citrus-flavored noodle product*). The item difficulties during pretest and posttest did not differ between male and female students.

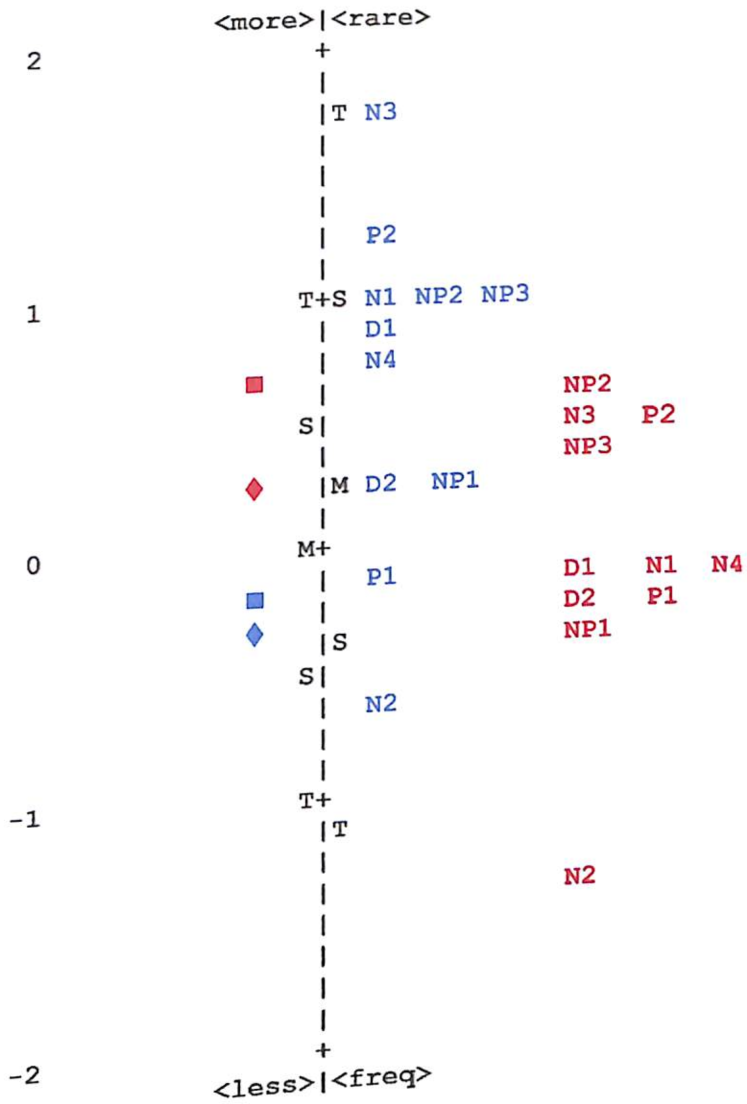


*Figure 4.9*. Wright map of CBHLT data in mereology-based instruction group showing pretest and posttest student ability and item difficulty

Item difficulties were derived from racked analysis. Mean abilities were derived from stacked analysis.

**Legend:** 🟦 Male students, pretest 🟥 Male students, posttest
◆ Female students, pretest ◆ Female students, posttest

Items in blue color are pretest items. Items in red color are posttest items.

Furthermore, Figure 4.9 shows that eight items (**N1**, *frying oil and diet plan*; **NP1**, (*milk product and heat-sensitive compound*); **N2**, *citrus-flavored noodle product);* **D1**, *urinalysis and metabolic disorder*, **NP3**, *product containing oxidizable compound*; **P2**, *fungal infection and antibacterial*; **N3**, *compound R in fruits*; and, **N4,** *compound J* *and food preparation*) decreased in item difficulty during posttest by more than 0.50 logit in the mereology-based instruction group.

In the conventional instruction group, four items (**N1**, *frying oil and diet plan*; **N2**, *citrus-flavored noodle product*, **P2**, *fungal infection and antibacterial*; and, **N3**, *compound R in fruits*) decreased in item difficulty by about 0.50 logit units (Table 4.6). One item (**P1**, *antibacterial drug and deactivation*) slightly increased in difficulty during posttest in the conventional instruction group.

Table 4.5 reveals that in the mereology-based instruction group, items which decreased in difficulty can be attributed to an increase in percentage of students who had level 2 and level 3 answers and a decrease in percentage of students who had level 0 and level 1 during posttest. It is also shown that the percentage increase of level 3 answers in all items were greater in favor of the mereology-based instruction group. Furthermore, there was a greater increase in level 2 answers in six items (**P1**, **D1**, **P2**, **N3**, **D2** and **N4**) in favor of the mereology-based instruction group, while three items (**N1**, **NP1**, and **NP3**) were observed to have higher percentage increase in level 2 answers, in favor of the conventional instruction group. It can be further noted that level 0 answers in the conventional instruction group increased in three items (items **P1**, **NP2**, and **D1**). The percentage increase in level 3 answers in the mereology-based instruction group was generally greater compared to the conventional instruction group, and the largest changes were attributed to three topics in nutrition (**N1**, **N2** and **N4**), followed by a topic in natural product evaluation (**NP1**).

## Table 4.6.

*Percentage of answers per level in chemistry-based health literacy test*

| Item | Level | MBI Group |  |  | CI Group |  |  |
|---|---|---|---|---|---|---|---|
|  |  | Pretest | Posttest | Difference | Pretest | Posttest | Difference |
| N1 | 0 | 31.03 | 17.59 | -13.45 | 34.84 | 23.00 | -11.85 |
|  | 1 | 52.76 | 38.97 | -13.79 | 54.36 | 49.83 | -4.53 |
|  | 2 | 14.14 | 17.93 | 3.79 | 9.06 | 14.98 | 5.92 |
|  | 3 | 2.07 | 25.52 | 23.45 | 1.74 | 12.20 | 10.45 |
| P1 | 0 | 16.21 | 14.48 | -1.72 | 20.21 | 24.74 | 4.53 |
|  | 1 | 49.66 | 32.41 | -17.24 | 47.04 | 40.07 | -6.97 |
|  | 2 | 12.76 | 25.52 | 12.76 | 15.33 | 14.63 | -0.70 |
|  | 3 | 21.38 | 27.59 | 6.21 | 17.42 | 20.56 | 3.14 |
| NP1 | 0 | 9.66 | 8.97 | -0.69 | 16.38 | 10.45 | -5.92 |
|  | 1 | 36.90 | 18.97 | -17.93 | 32.06 | 32.40 | 0.35 |
|  | 2 | 48.62 | 47.59 | -1.03 | 43.55 | 47.39 | 3.83 |
|  | 3 | 4.83 | 24.48 | 19.66 | 8.01 | 9.76 | 1.74 |
| N2 | 0 | 7.93 | 1.72 | -6.21 | 5.57 | 2.44 | -3.14 |
|  | 1 | 31.38 | 12.76 | -18.62 | 39.02 | 21.95 | -17.07 |
|  | 2 | 25.17 | 25.52 | 0.34 | 24.39 | 24.74 | 0.35 |
|  | 3 | 35.52 | 60.00 | 24.48 | 31.01 | 50.87 | 19.86 |
| NP2 | 0 | 33.10 | 33.10 | 0.00 | 36.93 | 41.81 | 4.88 |
|  | 1 | 24.14 | 21.03 | -3.10 | 23.34 | 19.86 | -3.48 |
|  | 2 | 41.03 | 38.62 | -2.41 | 37.98 | 35.19 | -2.79 |
|  | 3 | 1.72 | 7.24 | 5.52 | 1.74 | 3.14 | 1.39 |
| D1 | 0 | 21.72 | 7.93 | -13.79 | 20.91 | 21.25 | 0.35 |
|  | 1 | 59.66 | 46.21 | -13.45 | 56.10 | 54.36 | -1.74 |
|  | 2 | 16.55 | 33.79 | 17.24 | 17.77 | 14.98 | -2.79 |
|  | 3 | 2.07 | 12.07 | 10.00 | 5.23 | 9.41 | 4.18 |
| NP3 | 0 | 47.59 | 31.38 | -16.21 | 52.26 | 38.68 | -13.59 |
|  | 1 | 41.72 | 47.24 | 5.52 | 39.02 | 46.34 | 7.32 |
|  | 2 | 6.90 | 8.97 | 2.07 | 3.14 | 10.80 | 7.67 |
|  | 3 | 3.79 | 12.41 | 8.62 | 5.57 | 4.18 | -1.39 |
| P2 | 0 | 38.62 | 23.10 | -15.52 | 35.89 | 25.44 | -10.45 |
|  | 1 | 37.93 | 27.59 | -10.34 | 36.24 | 45.99 | 9.76 |
|  | 2 | 22.07 | 42.41 | 20.34 | 27.53 | 27.53 | 0.00 |
|  | 3 | 1.38 | 6.90 | 5.52 | 0.35 | 1.05 | 0.70 |
| N3 | 0 | 61.03 | 24.48 | -36.55 | 56.45 | 50.52 | -5.92 |
|  | 1 | 35.17 | 50.34 | 15.17 | 36.24 | 40.77 | 4.53 |
|  | 2 | 3.10 | 19.31 | 16.21 | 6.62 | 5.57 | -1.05 |
|  | 3 | 0.69 | 5.86 | 5.17 | 0.70 | 3.14 | 2.44 |
| D2 | 0 | 27.24 | 12.76 | -14.48 | 24.74 | 23.34 | -1.39 |
|  | 1 | 51.72 | 52.07 | 0.34 | 54.01 | 51.22 | -2.79 |
|  | 2 | 2.76 | 8.28 | 5.52 | 4.53 | 3.14 | -1.39 |
|  | 3 | 18.28 | 26.90 | 8.62 | 16.72 | 22.30 | 5.57 |
| N4 | 0 | 24.83 | 17.93 | -6.90 | 27.18 | 25.78 | -1.39 |
|  | 1 | 56.21 | 35.86 | -20.34 | 51.57 | 45.64 | -5.92 |
|  | 2 | 14.83 | 20.69 | 5.86 | 14.63 | 14.63 | 0.00 |
|  | 3 | 4.14 | 25.52 | 21.38 | 6.62 | 13.94 | 7.32 |

Please refer to Table 3.10 of Chapter 3 (page 83) for the characteristic of each level in chemistry-based health literacy test.

During posttest, students in the mereology-based instruction group use chemistry and non-chemistry explanations depending on the context of the item. Chemistry explanations involved analysis of chemical reactions, molecular interactions, or effects of heat to the stability of compounds were common in items **N1**, **N2**, **P1**, and **D1**. The concept of concentration and analysis of chemical composition and chemical reactions in biological samples, *in vivo* and *in vitro* data were commonly used in the explanations related to natural products (**NP1**, **NP2** and **NP3**) or diagnostic test (**D1**).

In some items, however, there were biased explanations related to any processed food, such as noodle product or juice. Processing was perceived as negative and was associated to preservatives and negative health effects. This was commonly used as an explanation in items **N2**, **N3** and **N4**. Seeking consultation or health advice from health care professionals was commonly used as non-chemistry explanation in items **NP2**, **P2** and **D2**, which require high-stake health decisions. Lastly, cost-effectiveness was also used to explain preference towards natural products over commercially-approved drugs, which is the case in item **NP2**. Most misconceptions were also related to chemistry concepts which are erroneously related to health concepts.

The changes in item difficulties indicate a change in the thinking process of the students. Based on the results, the thinking processes involved in mereology-based instruction may have increased proclivity towards a more cautious evaluation of information since they need to infer whether *part-whole* relations are valid based on attribution of properties. The increase in posttest ability and decrease in item difficulty in mereology-based instruction implies that the thought process of students have changed when concepts are related to health. Examples are given below.

**Item N1** (frying oil and diet plan)

MBI45, F, pretest
*Stable compounds allow the oil to be stable against heat and its properties so it can be used several times. It has preservatives, I think.*

MBI45, F, posttest
*The repeated use of frying oil at a certain temperature can make it undergo oxidation, and the fatty acid composition and property is changed. This in turn, can be harmful for human consumption as oxidation produces radicals.*

**Item P1** (Antibacterial drug and deactivation)

Student MBI 78, F, pretest explanation
*My mother tells us to drink medicine with water so I drink it with water.*

Student MBI 78, F, posttest explanation
*He should take the medication only with distilled water for this will not interfere with BioBrand B. It does not contain ions that will deactivate antibacterial drugs. It does not contain Mg2+ and Cu2+ that can affect the brand from working efficiently.*

However, the changes were varied depending on what topics are involved. To the author's knowledge, this study is the first to report *part-whole* relationship that addresses health literacy better than using *structure-activity* relationship in teaching biochemistry concepts.

Over-all, mereology-based instruction elicited more *category 3* answers compared to conventional instruction (Table 4.6). *Category 3* explanations include correct chemistry explanations in recognizing differences between *in vivo* and *in vitro* chemical environments, differences in chemical compositions, metabolism and describing molecular interactions. It was evident that certain topics in health (i.e., effect of frying on cooking oil, deactivation of antibacterial drug, limitations of *in vitro* or animal studies data in pharmacology) can be approached rigorously using chemistry-based reasoning, while some topics were approached based on existing preconceptions (i.e., issue on processed food, effect of food preparation on nutrient content). Some explanations, however, were clearly biased opinions based on "*entrenched beliefs.*" Others still, used heuristic reasoning in biochemistry.

There were differences on how students in both groups use chemistry concepts in certain items. It was common in the conventional instruction group to use molecular structures in their explanations in item **N1** (frying oil and diet plan) but reveals an alternative conception. For example, a double bond was thought to indicate stability, making oil stable to heat during frying. In contrast, students in mereology-based instruction explain that a "*double bond is a site for reactivity and oxidation.*" In item **NP3** (product containing oxidizable compound), a common exposition in the conventional instruction group is to associate oxygen in the structure of water molecule and conclude that water molecule is an oxidizing agent. On the other hand, students in the mereology-based instruction group rationalized that exposure to air causes oxidation, so the use of lotion and nasal spray should not be promoted. Lastly, students in the conventional instruction claim that brushing with salt removes stain in teeth because "*$NaCl$ reacts with calcium in teeth*" (item **D2**). These explanations were reminiscent of the students' wrong attribution of molecular property to differentiate bulk properties in chemical identity thinking.

There were also some common explanations in both groups. Despite several weeks of mereology-based instruction and conventional instruction, students still use preconceived notions when answering items. Students have deeply held concepts, which has been termed as an "*entrenched belief*" (Chinn and Brewer, 1993). For example, connecting negative attributions to terms is related to the report that "*chemicals*" are perceived negatively because these are associated to anything "*synthetic*" and "*potentially toxic or harmful*" (Edwards et al., 2016). This may explain why students in both groups prefer fresh foodstuff over anything which has undergone processing, even if the process does not involve addition of artificial preservatives. In addition, students associate the patient information to guide them in choosing their answers, even if this is not the context of the situation. An example is associating physiologic anemia with pregnancy. Students chose the option with iron supplements because of this information (item **N3**).

A similar case in this study is the association of "*fruit juice*" with fruit-flavored juice with preservatives (item **N3**). A fruit juice actually refers to freshly squeezed juice, a fruit concentrate, or pasteurized juice (Casswell, 2009). In fact, fruit juices have been reported to lower blood pressure and improves lipid profile (Zheng et al., 2017). It is possible that students perceive fruit juice as "*processed*" since most information about juice pertain to fruit-flavored juices. In the Philippines, fruit-flavored juice is more common than fresh fruit juice among school children and adolescents (Golloso-Gubat et al., 2015).

In addition, students associate a "*noodle product*" to "*instant noodles*", and further associate them to artificial preservatives in item **N2**. Overconsumption of instant noodle has been associated with cardiometabolic factors in Korean college students (Shin et al., 2017). However, in the Philippines, "*noodles*" refer to *miki, canton,* and *bihon,* which are used for preparing noodle dishes. The main concept addressed by item **N2** is the notion that citrus flavor used in instant noodle is not the same as vitamin.

If decision leads to immediate possible harm such as choice of medicine, students tend to base their decisions on medical advice or opinions of health care professionals. This was commonly used in items **NP2** (vasodilatation in rats), **P2** (fungal infection and antibacterial) and **D2** (teeth staining and antibacterial). This mindset promotes patient safety, but this can also be used to persuade health care students to display bias to anything which is promoted by health care professionals, even if the information is pseudoscientific or not evidence-based. Furthermore, if health care professionals are deployed in rural communities without access to health care, a poor chemistry-based health literacy among health care professionals can compromise the well-being of the community members.

Lastly, relying on cost of health care products such as medications, and not improving knowledge deficit or health literacy to guide decisions may lead to improper and inefficient choice of health care products and services (Palumbo, 2017). Lower cost was associated with lower dosage in item **NP2** and was used to justify those experimental natural products were good alternatives to a commercial drug. Cost is indeed a big factor in health literacy due to the sociodemographic characteristics of Filipinos, limiting their choice of health care products and services. But having the ability to select less expensive alternatives (i.e., eggs or mung beans over chicken and beef; health promotion over cure) is an important skill related to health literacy.

It is evident that misconceptions in some items were related to wrong applications of chemistry concepts to health concepts. However, the results imply that students are starting to use chemistry concepts to justify their explanations, and they no longer rely on unjustified or biased explanations. These are areas where scaffolding can be used to successfully link chemistry concepts to health literacy, thereby addressing chemistry-based health literacy. Over-all, both mereology-based instruction and conventional instruction increase chemistry-based health literacy, but it is highly idiosyncratic and the learning patterns are more similar to a meandering process rather than a linear progression.

Since it was revealed that there are statistically significant differences in the posttest logit abilities in in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy among students in the mereology-based instruction group and conventional instruction group, this study determined which variables significantly predict posttest ability in chemical identity thinking, critical thinking and chemistry-based health literacy in order to address the required learning characteristics of students to ensure a that learning has taken place when either mereology-based instruction or conventional instruction are used by a biochemistry teacher

### Predictors of Posttest Ability in Chemical Identity Thinking

The independent variables (PKCC ability, PKVR ability, pretest ability in CIT, average total cognitive load, and gender) statistically significantly predict chemical identity thinking posttest ability logit in the mereology-based instruction group, $F_{(5, 284)}=17.033$, $p=0.000$, $R^2=0.231$, Cohen's $f^2=0.300$. Similarly, the independent variables also predict the chemical identity thinking posttest ability logit in the conventional instruction group, $F_{(5, 281)}=11.179$, $p=0.000$, $R^2=0.166$, Cohen's $f^2 = 0.199$. Note that the effect sizes were moderate.

Table 4.7 shows that prior knowledge of chemistry concepts and pretest ability in chemical identity thinking predict an improvement in chemical identity thinking in both groups. In the mereology-based instruction group, gender was also a significant predictor, favoring male students although gender was not a significant predictor of posttest ability in the conventional instruction group.

**Table 4.7.**

*Predictors of chemical identity thinking in mereology-based instruction group and conventional instruction group based on multiple linear regression analysis*

| Group | Independent Variables | B | SE | β | p |
|---|---|---|---|---|---|
| **Mereology-based Instruction Group** | Constant | 0.605 | 0.152 | | |
| | PKCC ability | 0.325 | 0.076 | 0.261 | **0.000** |
| | PKVR ability | -0.030 | 0.050 | -0.306 | 0.553 |
| | Pretest ability in CIT | 0.317 | 0.057 | 0.303 | **0.000** |
| | Average Total Cognitive Load | 0.036 | 0.043 | 0.045 | 0.405 |
| | Gender | -0.228 | 0.082 | -0.149 | **0.006** |
| **Conventional Instruction Group** | Constant | 0.053 | 0.095 | | |
| | PKCC ability | 0.181 | 0.053 | 0.207 | **0.001** |
| | PKVR ability | 0.060 | 0.038 | 0.096 | 0.111 |
| | Pretest ability in CIT | 0.189 | 0.040 | 0.260 | **0.000** |
| | Average total cognitive load | 0.045 | 0.031 | 0.079 | 0.152 |
| | Gender | 0.001 | 0.053 | 0.001 | 0.980 |

To the author's knowledge, this is the first attempt to determine the significant predictors of chemical identity thinking after performing Rasch analysis. Chemical identity thinking was patterned from the study of Ngai et al. (2016), who established a learning progression: *objectivization*, *principlism*, *compositionism*, and *interactionism*. Based on the results in Table 4.7., it is apparent that certain variables are significant predictors depending on the type of instruction used. What is common for both types of instruction is the significant positive prediction of prior knowledge of chemistry concepts and pretest ability in the chemical identity thinking instrument. Gender, on the other hand, is a significant predictor to the mereology-based instruction group only.

Prior knowledge of chemistry concepts influences the ability of students to differentiate substances as basic chemistry knowledge is the core of sophisticated chemistry reasoning when differentiating substances. With a positive beta coefficient ($\beta$), the model suggests that higher prior knowledge in chemistry leads to better posttest chemical identity thinking student ability when taught using either mereology-based instruction or conventional instruction.

The depth to which each substance is differentiated is linked to the ability to use previously learned chemistry concepts (Silva & Batista, 2003). However, health science programs may be a special case since the program requires a multidisciplinary approach in learning health concepts, which explains why the differentiation of substances may also be based on health contexts. Lastly, while it was previously reported that there is no influence of background knowledge in biology and chemistry to learning biochemistry (Minasian-Batmanian et al., 2006), it is argued in this study that prior knowledge in chemistry is an important factor to determine the trajectory of learning of students in biochemistry, as biochemistry concepts build on prior conceptual understanding of chemistry concepts.

Pretest ability in chemical identity thinking emerged as a significant predictor or posttest chemical identity thinking student ability. Including pretest ability in a linear regression model helps explain the changes in student ability in chemical identity thinking. With a significant positive beta coefficient ($\beta$), the linear regression model indicates that a higher pretest student ability logit leads to higher posttest student ability logit. It has to be considered that in this study, Rasch analysis was employed using stacked analysis to correctly reflect the changes in posttest student ability when compared to the pretest student ability. While it is true that learning gains using raw scores are erroneous or prone to misinterpretation due to the non-linear nature of the data (Bond & Fox, 2007; Boone & Notelmeyer, 2017), using student ability logits is a more accurate measure of the predictive nature of pretest ability to a student's posttest ability, and is highly recommended to measure learning gains (Planinic et al., 2019). The positive prediction of pretest ability in chemical identity thinking implies that previous chemistry subjects need to strengthen the ability of students to classify substances based on their attributes, to ensure an enhancement of chemical identity thinking when taught with either mereology-based instruction or conventional instruction.

Male gender emerged to be a significant predictor of posttest ability in chemical identity thinking when taught using mereology-based instruction. However, it is acknowledged in this study that gender *per se* may not be a sufficient basis to generalize the male gender as having greater potential to exhibit greater potential in exhibiting higher levels of chemical identity thinking because the differentiation of substances requires the interaction of a student's cognitive abilities and non-cognitive characteristics. However, it is worthy to note that male students have been reported to exhibit generally higher achievement in chemistry (Forbes-Lorman et al., 2016; Rauschenberger & Sweeder, 2010; Veloo et al., 2015). Since mereology-based instruction was based on a *part-whole* relationship, it is possible that higher achievement in chemistry offers a greater advantage to successfully differentiate substances due to initial familiarity with relevant chemistry concepts.

## Predictors of Posttest Ability in Critical Thinking in Chemistry

The model for predictors of chemistry posttest ability logit was significant in the mereology-based instruction group, $F_{(5, 284)}$=32.549, $p$=0.000, $R^2$=0.364, Cohen's $f^2$ = 0.572. Similarly, the model of predictors for the chemical identity thinking posttest ability logit in the conventional instruction group was also significant, $F_{(5, 281)}$=26.769, $p$=0.000, $R^2$=0.323, Cohen's $f^2$ = 0.477. Note that the effect sizes are large.

Table 4.8 shows that prior knowledge of chemistry concepts, prior knowledge of visual representations and pretest student ability in critical thinking in chemistry were significant predictors of posttest critical thinking student ability in both mereology-based instruction group and conventional instruction group. Gender was a significant predictor of posttest ability in the conventional instruction group, favoring males, but is not a significant predictor in the mereology-based instruction group.

Prior knowledge is a positive predictor or posttest critical thinking in chemistry based on the beta coefficient ($\beta$). This is supported by the items in the critical thinking test in chemistry, which are all based on chemistry concepts. Hence, prior knowledge is expected to be a conceptual basis when answering items which require higher order thinking skills in chemistry. The students' prior knowledge of visual representations is a positive predictor of posttest critical thinking in chemistry based on a positive beta coefficient ($\beta$). Visual representations are often required to make inferences about chemical reactions and other chemical phenomena. In fact, visual representations in chemistry range from simple structural features of biological molecules (Harle & Towns, 2013; Li & Koehl, 2014; Linenberger & Bretz, 2014; Mnguni et al., 2016) to other dynamic chemical features such as molecular interactions and processes (Bussey & Orgill, 2015). Hence, prior knowledge of visual representations is relevant when analyzing items which require higher order thinking skills.

**Table 4.8.**

*Predictors of critical thinking in chemistry in mereology-based instruction group and conventional instruction group based on multiple linear regression analysis*

| Group | Independent Variables | B | SE | *β* | *p* |
|---|---|---|---|---|---|
| **Mereology-based Instruction Group** | Constant | 0.228 | 0.141 | | |
| | PKCC ability | 0.164 | 0.072 | 0.132 | **0.024** |
| | PKVR ability | 0.133 | 0.045 | 0.162 | **0.004** |
| | Pretest ability in CTC | 0.512 | 0.067 | 0.415 | **0.000** |
| | Average Total Cognitive load | -0.003 | 0.039 | -0.003 | 0.944 |
| | Gender | -0.130 | 0.076 | -0.084 | 0.088 |
| **Conventional Instruction Group** | Constant | 0.039 | 0.121 | | |
| | PKCC | 0.280 | 0.067 | 0.235 | **0.000** |
| | PKVR | 0.145 | 0.047 | 0.169 | **0.002** |
| | Pretest Ability in CTC | 0.313 | 0.070 | 0.252 | **0.000** |
| | Average Total Cognitive Load | 0.066 | 0.038 | 0.085 | 0.089 |
| | Gender | -0.208 | 0.066 | -0.161 | **0.002** |

Pretest ability in critical thinking in chemistry is also a positive predictor of posttest ability in critical thinking in chemistry based on the positive beta value ($\beta$). Furthermore, it has the highest contribution to the model based on the beta coefficient. This implies that mereology-based instruction and conventional instruction can increase the critical thinking of students in chemistry and the improvement is also higher if students already have an adequate pretest ability. Since Rasch partial credit model with stacked analysis was used to obtain the pretest student ability logits and posttest ability logits, there is a higher accuracy of the model to predict the likelihood of correctly providing accurate and sophisticated reasoning in chemistry concepts. Since this model is only delimited to one institution, there is an opportunity to validate the contribution of pretest ability in critical thinking in other health science programs.

Gender is a significant predictor of posttest ability logit of critical thinking in chemistry in the conventional instruction group, favoring males. It is reiterated again that in this study, the ability of male students to associate chemistry concepts (Gulacar, 2019) is a plausible reason why males may outperform female students in the conventional instruction group. It is noted that a *structure-property* relationship or a *structure-function* relationship involves association of concepts. However, the positive prediction of male gender to posttest student ability logit in critical thinking in chemistry may warrant additional validation in various contexts.

### Predictors of Posttest Ability in Chemistry-based Health Literacy

The model of predictors is statistically significant in the mereology-based instruction group, $F_{(5, 284)}$=18.681, $p$=0.000, $R^2$=0.247, Cohen's $f^2$ = 0.328. Similarly, the model in conventional instruction group was also significant, $F_{(4, 282)}$=23.462, $p$=0.000, $R^2$=0.295, Cohen's $f^2$ = 0.418. Note that the effect size in mereology-based instruction was moderate and the effect size in the conventional instruction group was large. Table 4.9 shows that prior knowledge of chemistry concepts and pretest ability in chemistry-based health literacy were significant predictors of posttest ability in chemistry-based health literacy. In the mereology-based instruction group, average total cognitive load and gender were also significant predictors, favoring male students.

**Table 4.9.**

*Predictors of chemistry-based health literacy in mereology-based instruction group and conventional instruction group using multiple regression analysis*

| Group | Independent Variable | B | SE | β | p |
|---|---|---|---|---|---|
| Mereology-based Instruction Group | Constant | 0.828 | 0.175 | | |
| | PKCC | 0.144 | 0.086 | 0.100 | 0.095 |
| | PKVR | 0.128 | 0.057 | 0.135 | **0.025** |
| | Pretest ability in CbHL | 0.465 | 0.062 | 0.393 | **0.000** |
| | Average Total Cognitive Load | 0.102 | 0.049 | 0.109 | **0.041** |
| | Gender | -0.233 | 0.094 | -0.132 | **0.013** |
| Conventional Instruction Group | Constant | -0.141 | 0.120 | | |
| | PKCC | 0.102 | 0.065 | 0.178 | **0.001** |
| | PKVR | 0.051 | 0.047 | 0.060 | 0.280 |
| | Pretest Ability in CbHL | 0.445 | 0.051 | 0.461 | **0.000** |
| | Average Total Cognitive Load | -0.024 | 0.039 | -0.032 | 0.536 |
| | Gender | 0.038 | 0.066 | 0.030 | 0.567 |

The measurement of chemistry-based health literacy among health science students in both mereology-based instruction and conventional instruction is a novel contribution of the study to biochemistry education, and developing a model which identifies all possible predictors of increased posttest student ability logit is an excellent point of reference for those who wish to investigate the construct in various settings. Based on the models, pretest ability in chemistry-based health literacy is a positive predictor in both mereology-based instruction and conventional instruction. It is interesting to note that prior knowledge of chemistry concepts is a predictor of posttest ability in chemistry-based health literacy among students which were taught with conventional instruction in chemistry.

However, there are stark differences on the predictors of chemistry-based health literacy in mereology-based instruction and conventional instruction. If biochemistry concepts are to be approached using mereology-based instruction, several variables contribute to the posttest student ability in chemistry-based health literacy. These include prior knowledge of visual representations, average total cognitive load, and average total cognitive load. Furthermore, gender is also a predictor of posttest ability of chemistry-based health literacy, favoring males.

This indicates that there is a cognitive requirement when biochemistry concepts are taught using mereology-based instruction. Since the beta coefficients are positive, it implies that interventions which ensure adequate prior knowledge visual representations, and pretest ability in chemistry-based health literacy need to be considered, if students are honed to gain greater chemistry-based health literacy at the end of the teaching intervention. The contribution of gender to the model indicates that the learning characteristics of male seems to be appropriate for mereology-based instruction, and may warrant further investigation. Hence, a discussion on the cognitive load of students in both mereology-based instruction group and conventional instruction group are explored comprehensively.

Based on the beta coefficient in the model for predictors of increased chemistry-based health literacy in mereology-based instruction, an increased average total cognitive load also increases posttest student ability in chemistry-based health literacy. However, using a *structure-property* relationship or *structure-function* relationship also presents a high cognitive load as it requires simultaneous analysis of the sub-microscopic, symbolic and macroscopic domain of chemistry. However, average total cognitive load does not contribute to the model for the prediction of posttest ability in chemistry-based health literacy among students in the conventional instruction group. Along with the previous data on higher posttest ability of students in chemistry-based health literacy in the mereology-based instruction group, the model provides a lot of possible issues to be addressed if chemistry-based health literacy is considered as a learning outcome among students.

The inclusion of average total cognitive load among the predictors of posttest chemistry-based health literacy among students in the mereology-based instruction group warrants an additional discussion, and is investigated further. Students in the MBI group indicated that the cognitive load in the activities they performed was high (Figure 4.10), however they obtained higher posttest student ability logits. It is inferred that overcoming a high cognitive load associated with mereology-based instruction is required to gain more chemistry-based health literacy. On the other hand, there are studies in chemistry education indicating that reducing the cognitive load results to better learning outcomes (Behmke & Atwood, 2013; Costley et al., 2020; Milencovic et al., 2014). Since mereology-based instruction presents a higher cognitive load, the results contribute a novel finding to chemistry education. Assisting students to overcome the cognitive load, not the initial cognitive load, contributes to positive learning outcomes.

The mean item difficulty logits related to total cognitive load vary in each laboratory activity (Figure 4.10), but there is an increasing trend from Activity 04 to Activity 10. Generally, the mean item difficulty in the mereology-based instruction group is greater compared to the conventional instruction group, except for Activity 05 (E-ring Modified Steroids and 17β-Hydroxysteroid Dehydrogenase Type 1 Inhibition). A decreasing mean item difficulty implies a decreasing total cognitive load experienced by students. In both groups, the mean logit of total cognitive load was highest in Activity 05.

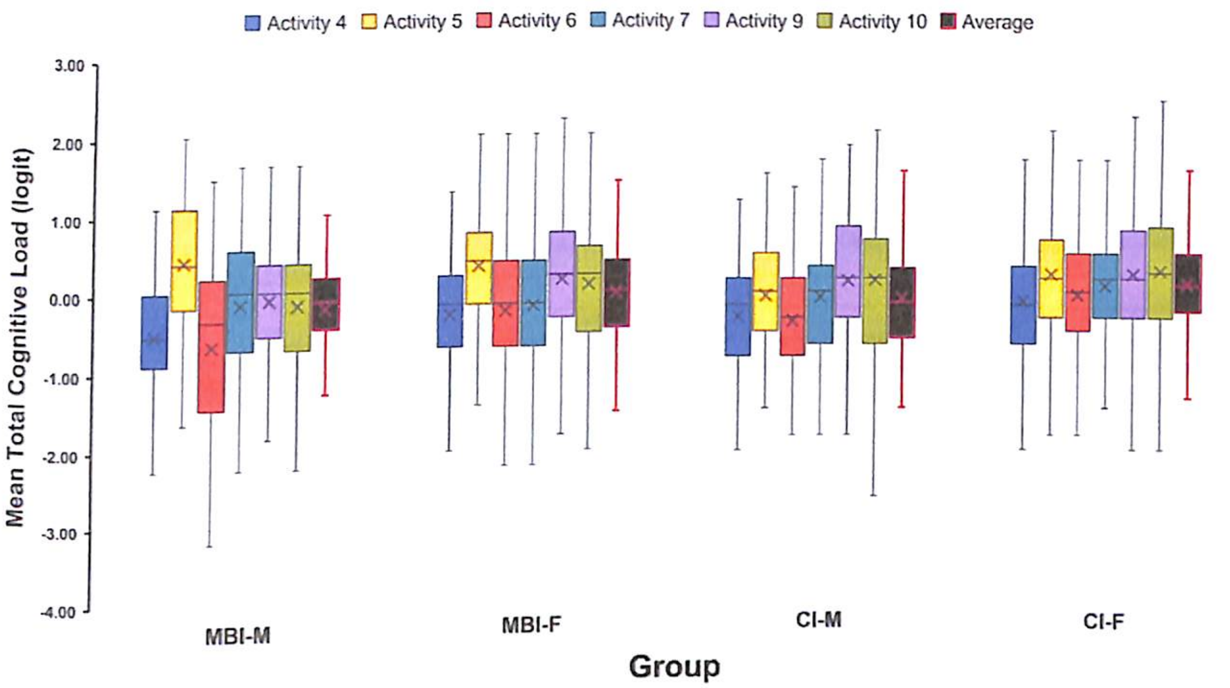


*Figure 4.10.* Mean total cognitive load experienced by students per laboratory activity in contrast to average total cognitive load

In this study, the average total cognitive load is divided into intrinsic cognitive load (ICL), extraneous cognitive load related to the feature of activity (ECL-F), extraneous cognitive load related to task (ECL-T), germane cognitive load related to mental effort (GCL-ME) and germane load related to enhancement of understanding (GCL-EU) in the mereology-based instruction group and conventioanl instruction group are shown in Figure 4.11. It can be observed that students who were taught with mereology-based instruction had higher intrinsic, extraneous and germane cognitive load compared to students who were taught with conventional instruction. Germane cognitive load related to enhancement of understanding had the highest cognitive load while germane load related to mental effort was the lowest in both types of instruction. Furthermore, cognitive load in extraneous load was higher than intrinsic cognitive load.

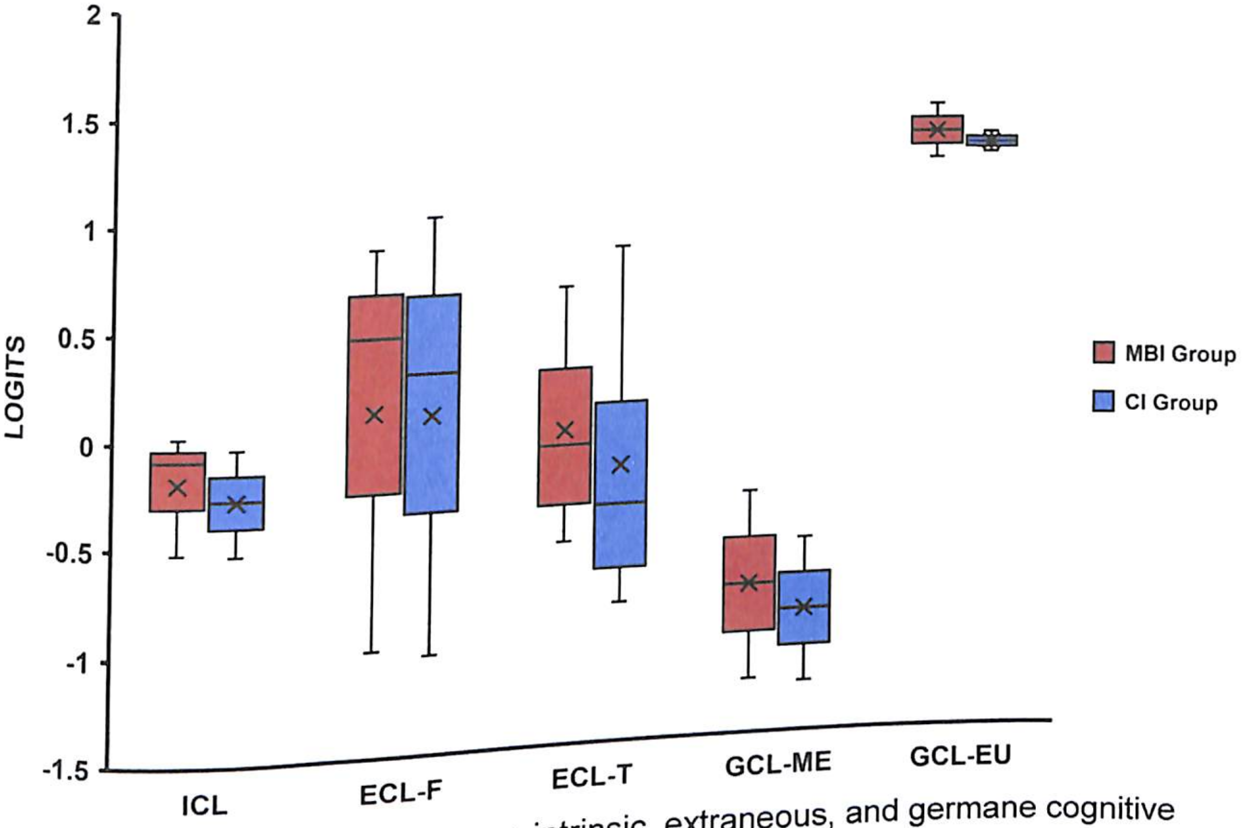


*Figure 4.11*. Comparison of average intrinsic, extraneous, and germane cognitive load in mereology-based instruction group and conventional instruction group

It is shown in Figure 4.12 that the students in the mereology-based instruction group experienced more cognitive load compared to students in the conventional instruction group. It is notable that in item 6 (*clarity of laboratory activity instructions*) and item 10 (*ease of SPR/ SAR with visual representations*), there was higher cognitive load experienced by students in the conventional instruction group.

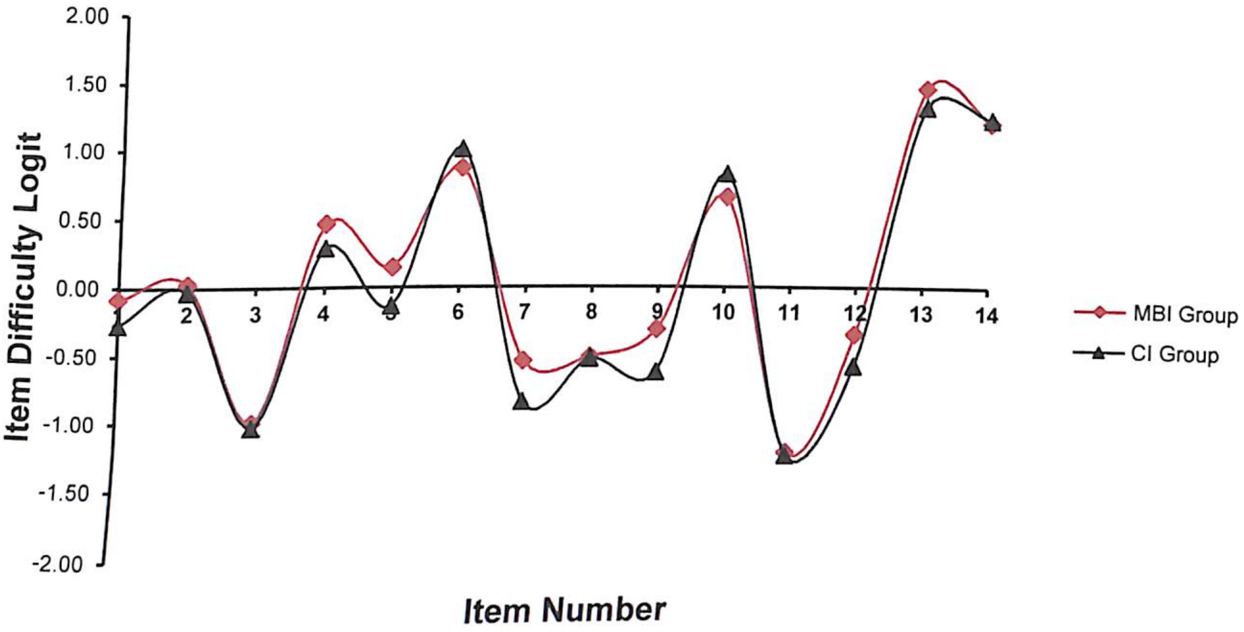


*Figure 4.12.* Comparison of item-specific cognitive load between mereology-based instruction group and conventional instruction group

In the studies of Behmke and Atwood (2013) and Milenkovic et al. (2014), an increased learning gain in chemistry was supported by decreased cognitive load. However, this is not supported in this study, as higher cognitive load in mereology-based instruction resulted to higher learning gains in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy. However, it can be claimed that a decreasing trend in total cognitive load and in its sub-components seems to be characterized by higher posttest student ability in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy.

This implies that if students overcome the cognitive load related to laboratory activities, they may gain more understanding of biochemistry and other related concepts. It is evident in this study that indeed, all sub-components of total cognitive load displayed a decreasing trend from Activity 04 to Activity 10, suggesting that students have learned to perform *in vitro* laboratory activities, *in silico* activities and class argumentation, even when more complex molecules at the latter part of each activity are involved.

According to Jones et al. (2014), undergraduate students do not adapt immediately to an approach such as mereology-based instruction and may use surface learning initially. But if the students become familiar with the thinking process, they may approach concepts critically, so total cognitive load may decrease over time, as shown in the results. This study supports the claim that cognitive processing can still happen even if cognitive load is high (Costley et al., 2020), but an interpretation should not be based on causation, but on concurrent description of what happens during the learning process, as well as the cognitive load felt by students during instruction.

One explanation for this is the exploratory nature and inquiry-based nature of investigating *part-whole* relationship in biochemistry. Most journal articles and textbooks do not explicitly reveal part-whole relationships in chemistry. Furthermore, students also need to navigate and relate ontological contexts of mereology to chemistry contexts to answer arguments, laboratory activities, and research questions using this thinking. Students in the mereology-based instruction group were also addressing reductionist claims using part-whole relationships.

On the other hand, conventional instruction was based on using *structure-property* and *structure-activity* explanations, which were actually more similar in framework to the quantitative *structure-activity* relationship (QSAR) that the students were performing in the laboratory activities. This could also be the reason for a higher germane cognitive load in the mereology-based instruction group, as QSAR activities do not explicitly reveal *part-whole* relationships.

It is not surprising that the total cognitive load in Activity 05 is higher in the mereology-based instruction group than in the conventional instruction group. This activity was related to an *in-silico* analysis of E-ring Modified Steroids and 17β-Hydroxysteroid Dehydrogenase Type 1 Inhibition, which is quite complex since it involves the use of online software such as MolView, and ChemDes, and extensive use of Microsoft Excel for data analysis. But, compared to other molecules, this activity dealt with changing the substituents to the E-ring of a single hydroxysteroid molecule, and not dealing with molecules with different structures. This activity involved complex visual representations, in general.

## Contributions to Existing Theory

Based on the results in this section, there are contributions of this current study to the theories identified in Chapter 2. With respect to the cognitive dissonance theory, if the information challenges preconceptions, consumer concerns and negative association between chemistry and health needs, the information can be used to address chemistry-based health literacy. The presence of these contexts in chemical identity thinking indicates that students link chemical identity with chemistry-based health literacy. In addition, failure to link chemistry to health literacy may promote reliance on health care professionals only, especially if health decisions lead to increased risk of injury.

With respect to the cognitive load theory, this study does not support that lower cognitive load results to higher learning gains or higher posttest abilities in chemical identity thinking and critical thinking in chemistry. Cognitive load, based on the results, varies per student. With respect to chemistry-based health literacy, this study asserts that learning gains are met if students successfully overcome the embedded intrinsic and extraneous cognitive load in the mereology-based instruction activities, while overcoming germane cognitive load may take a longer time or training.

Lastly, considering the situated learning theory, the results show that students learn concepts not by progression, but by a meandering pattern, given that students were not deliberately taught with content in mereology-based instruction. Furthermore, the thinking process from a chemistry context influences the thinking process in chemistry-based health literacy, but there is more influence of biochemistry context than the ontological context in the explanations. Hence, the thinking process presented in Chapter 2 is modified and shown in Figure 4.13.

In the revised model, increased prior knowledge of chemistry concepts, pretest ability in chemical identity thinking, and gender increase chemical identity thinking at the post-intervention. Increased prior knowledge of chemistry concepts, prior knowledge of visual representations and pretest ability in critical thinking in chemistry increase post-intervention critical thinking in chemistry. Increased cognitive load, prior knowledge of visual representations, pretest ability in chemistry-based health literacy and gender increase chemistry-based health literacy post-intervention. The contexts of explanations and answers of students who participated in mereology-based instruction were influenced by preconceptions, consumer concerns, negative concept associations between chemistry and health, and reliance on health professionals.

Based on the findings, the conceptual framework is revised to show the impact of prior knowledge of chemistry concepts, prior knowledge of visual representations, gender, cognitive load, and pretest ability to chemical identity thinking, critical thinking and chemistry-based health literacy when the biochemistry concepts are taught using mereology-based instruction (using *part-whole* relationship) and conventional instruction (using *structure-property and structure-function* relationship). The revised conceptual framework is shown in Figure 4.14.

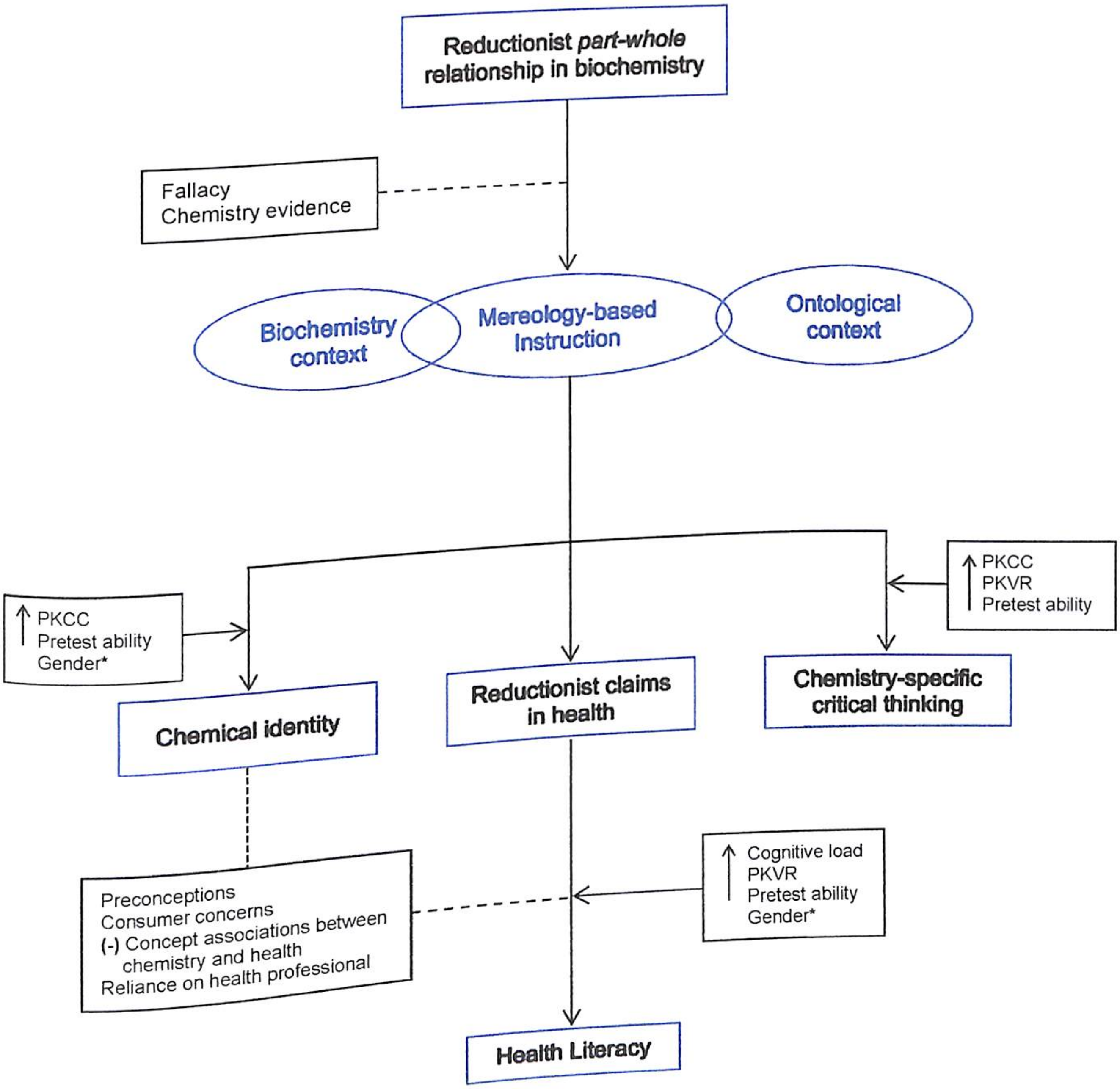


*Figure 4.13.* Revised thinking process in mereology-based instruction and effects on chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy

*Effect may be attributed to learning characteristics related to gender, not gender *per se*
Upward arrow (↑) indicates an increase in the indicated variable.

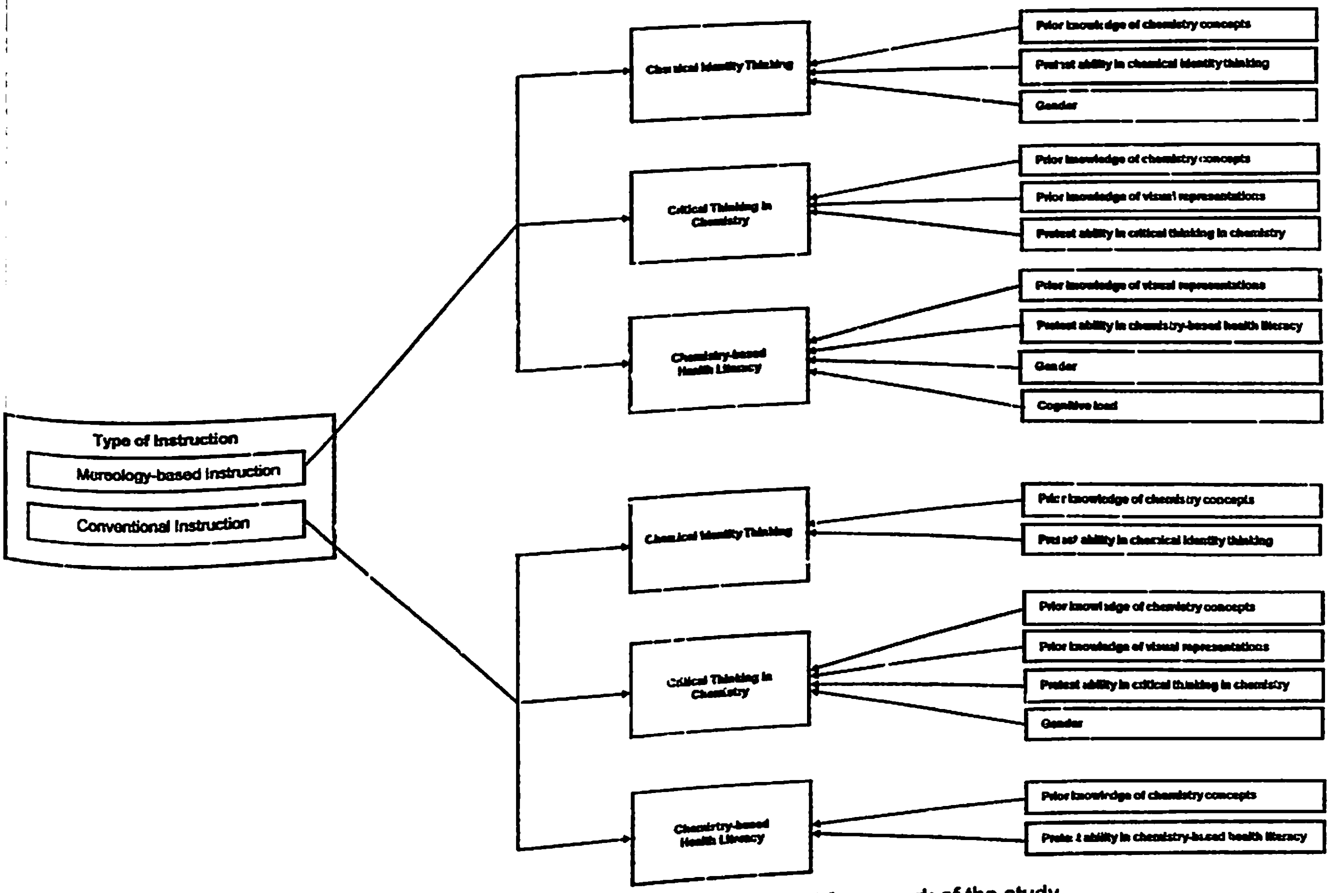


*Figure 4.14.* Revised conceptual framework of the study

# CHAPTER 5

# SUMMARY, CONCLUSION AND RECOMMENDATIONS

This chapter presents the summary and conclusion of the study regarding the effect of mereology-based instruction to chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy among health science students. The differences on cognitive load are also included. In addition, this chapter provides recommendations for chemistry education researchers who would like to investigate health science students in the context of chemistry education research.

The study was conducted last August to November of AY 2019-2020 to thirteen intact classes in a university in Baguio City. A total of 577 participants comprised of 280 students in mereology-based instruction group (17.50% males, 82.50% females), and 277 students in conventional instruction group (22.65% males, 77.35% females) participated in this study.

Mereology-based instruction and conventional instruction were implemented for 12 weeks within August to November 2019. Each week is equivalent to three days of one-hour lecture sessions and two-hour laboratory sessions. A total of six argumentation activity and six quantitative structure-activity relationship activities were performed during laboratory sessions. Mereology-based instruction involved the utilization of *part-whole* relationships in argumentation and laboratory activities while conventional instruction involved the utilization of *structure-property/structure-function* relationship. Prior to the actual implementation of the interventions, all student-participants underwent a training in performing basic analysis of molecular descriptors using ChemDes and MolView, Microsoft Excel, and quantitative image analysis using the software ImageJ. A five-day training-workshop was conducted to seven prospective Biochemistry instructors to train them on how to use MolView, ChemDes, statistical analysis in Microsoft Excel, performance of laboratory assays, and evaluation of written arguments. The Biochemistry instructors were also oriented on how to use the lecture learning material and laboratory manual. Mereology-based instruction was based on part-whole relationship, while conventional instruction was based on structure-property relationship and structure-function relationship.

This study utilized Rasch analysis to measure the effects of type of instruction to chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy. In addition, Rasch analysis was also used to determine the prior knowledge of chemistry concepts, prior knowledge of visual representations, and cognitive load.

Rasch analysis is an approach of mathematical modelling based on a latent trait and involves the measurement of person ability and item difficulty in one linear scale, called the logit scale. The data in the study is expressed into logit or "log-odd unit", which is a linear unit of measurement derived from estimation of person ability and item difficulty. Data on student ability and item difficulty were converted into logits using dichotomous Rasch analysis for prior knowledge of chemistry concepts and prior knowledge of visual representations. To obtain student ability and item difficulty in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy, Rasch partial credit modelling was utilized. In order to determine total, extraneous, intrinsic and germane cognitive load, Rasch rating scale model was utilized.

In order to compare pretest and posttest student ability logits in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy, stacking of the data set was performed. Stacking is a procedure which involves the analysis of pretest and posttest student ability logit using items as common anchors.

To determine changes in pretest-posttest item difficulty, racking was utilized. Racking involves analysis of item difficulty logits using student ability as anchor.

## Summary

This study aimed to determine the effects of mereology-based instruction to chemical identity thinking, critical thinking and chemistry-based health literacy of second year medical laboratory science students, in comparison to conventional instruction, which is based on *structure-property* or *structure-function* relationships.

Both the mereology-based instruction group and the conventional instruction group were immersed in quantitative structure-activity relationship laboratory activities with *in vitro* and *in silico* activity components. In addition, the format of argumentation using Toulmin Argumentation Pattern were similar to both groups, and the lecture notes were identical. The only difference is the type of approach used in their argumentation and research questions.

The approach in mereology-based instruction group is *part-whole* relationship while in the conventional instruction group, students used the approach of *structure-property* and *structure-function* relationship. Furthermore, mereology-based instruction did not focus on teaching part-whole relationship, but opportunities to evaluate reductionist claims using the *part-whole* relationship schema.

This study has satisfactorily answered each research question related to the effects of mereology-based instruction to chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy within the context of biochemistry education in a health science program. The summary of findings is presented as follows in response to the research questions put forth at the beginning of the study.

**What is the level of difficulty of items related to prior knowledge of chemistry concepts and prior knowledge of visual representations in the mereology-based instruction (MBI) group and conventional instruction (CI) group?**

Over-all, the level of difficulty of both prior knowledge of chemistry concepts test and visual representations test are within the student abilities of the participants. The mean difficulty of items related to prior knowledge of chemistry concepts is 0.11 logit units above the mean student ability logit. Out of the 45 items in the prior knowledge of chemistry concepts test (PKCCT), 17 items were below the mean person ability, which implies that the items in the research instrument are appropriate for the abilities of the student-participants. Items related to general organic chemistry concepts have the highest mean item difficulty logits while general inorganic chemistry concepts had the lowest mean item difficulty logits.

The mean item difficulty of prior knowledge of visual representations test is 0.29 logits above the mean student ability logit, indicating that the difficulty of items in the test is appropriate for the abilities of the student-participants. Out of the 23 items in the visual representations test, 7 items were below the mean person ability. Items related to ball and stick models have the highest mean item difficulty logits while items involving skeletal structures have the lowest mean item difficulty. These findings suggest that visual representations involving three-dimensional models are more difficult to interpret than two-dimensional models.

**After controlling for prior knowledge of chemistry concepts and prior knowledge of visual representations, is there a significant difference between students exposed to MBI and to CI in terms of posttest chemical identity thinking (CIT), posttest critical thinking in chemistry (CTC) and posttest chemistry-based health literacy (CbHL)?**

Both mereology-based instruction and conventional instruction increase the posttest ability of students in chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy. Compared to conventional instruction, mereology-based instruction resulted to statistically significantly higher mean posttest ability logits of male and female students in chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy, after controlling for ability logits in prior knowledge of chemistry concepts, prior knowledge of visual representations and pretest ability in the aforementioned variables.

Over-all, there was a greater decrease in mean item difficulty logits in the mereology-based instruction group compared to conventional instruction group in chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy. Out of the 20 items related to chemical identity thinking, 14 items have decreased posttest item difficulty logits in the mereology-based instruction group while 9 items have decreased posttest item difficulty logits in the conventional instruction group. Out of the 18 items related to critical thinking in chemistry, 14 items decreased in posttest item difficulty in the mereology-based instruction group. In the conventional instruction group, 11 items decreased in posttest item difficulty logits. Out of 11 items related to chemistry-based health literacy, all items have lower posttest item difficulty in the mereology-based instruction group, with 8 items having more than 0.50 item difficulty logit difference from the pretest item difficulty logits. In the conventional instruction group, all items also had lower posttest item difficulty logits, but only 4 items have more than 0.50 item difficulty logit difference from the pretest item difficulty logit. In addition, one item increased in posttest item difficulty by in the conventional instruction group. These findings suggest that the effect of type of intervention to changes in item difficulty are topic-specific.

**Taken simultaneously, are the variables gender, prior knowledge of chemistry concepts, prior knowledge of visual representations, pretest ability in chemical identity thinking (CIT), and mean total cognitive load positive predictors of posttest ability in chemical identity thinking (CIT)?**

In the mereology-based instruction group, the significant predictors for posttest ability in chemical identity thinking were prior knowledge of chemistry concepts, pretest ability in chemical identity thinking and gender, favoring male students, when all variables are taken simultaneously. In the conventional instruction group, only the prior knowledge of chemistry concepts and pretest ability in chemical identity thinking are significant predictors.

**Taken simultaneously, are the variables gender, prior knowledge of chemistry concepts, prior knowledge of visual representations, pretest ability in critical thinking in chemistry (CTC), and mean total cognitive load positive predictors of posttest ability in critical thinking in chemistry (CTC)?**

In the mereology-based instruction group, the significant predictors for posttest ability in critical thinking in chemistry were prior knowledge of chemistry concepts, prior knowledge of visual representations, and pretest ability in critical thinking in chemistry, when all variables are taken simultaneously. In the conventional instruction group, the significant predictors for posttest ability in critical thinking in chemistry were prior knowledge of chemistry concepts, prior knowledge of visual representations, pretest ability in critical thinking in chemistry, and gender, favoring male students.

**Taken simultaneously, are the variables gender, prior knowledge of chemistry concepts, prior knowledge of visual representations, pretest ability in chemistry-based health literacy (CbHL), and mean total cognitive load positive predictors of posttest ability in chemistry-based health literacy (CbHL)?**

In the mereology-based instruction group, the significant predictors for posttest ability in critical thinking in chemistry were prior knowledge of chemistry concepts, pretest ability in chemistry-based health literacy, average total cognitive load, and gender favoring male students, when all variables are taken simultaneously. In the conventional instruction group, the significant predictors for posttest ability in chemistry-based health literacy were prior knowledge of chemistry concepts, and pretest ability in chemistry-based health literacy only.

## Conclusion

In the context of biochemistry instruction in the health science program such as medical laboratory science, mereology-based instruction is more effective than conventional instruction in increasing student ability in chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy of students. Participants in the mereology-based instruction, however, perceived greater total, extraneous, intrinsic and germane cognitive load compared to the participants in the conventional instruction group. Mereology-based instruction, in general, promotes greater increase in posttest student ability logits of male students compared to females. The varying decrease in item difficulty logits in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy suggests that both mereology-based instruction and conventional instruction have topic-specific effects. Furthermore, mereology-based instruction has an "enhancement" effect in chemical identity thinking, "corrective" effect in critical thinking in chemistry, and either "corrective" or "enhancing" effect in chemistry-based health literacy based on the changes in levels corresponding to category thresholds in the aforementioned constructs. Conventional instruction has a "corrective" effect in chemical identity thinking, critical thinking in chemistry, and chemistry-based health literacy. An increase in posttest student ability in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy can be predicted by a varied combination of prior knowledge of chemistry concepts, prior knowledge of visual representations, pretest student ability, mean total cognitive load and gender.

## Implications of the Study

The findings of the study can be used by curriculum developers of chemistry courses in choosing a philosophical theme in chemistry that could be used to supplement student learning. First, a philosophical theme has the potential to support the development of critical thinking and health literacy among health science students because chemistry concepts are analyzed concurrently with health concepts and logic in reasoning. Second, there is a high potential for the application of quantitative structure-activity relationship laboratory activities in the health sciences because it promotes higher order thinking skills instead of the cookbook approach in teaching, which currently abound in the health sciences.

Curriculum developers can also design new subjects which incorporate philosophy of chemistry to health-related chemistry subjects such as organic chemistry and biochemistry to serve as a lens to describe the nature of chemical entities. Lastly, curriculum developers could also design which subjects should be offered concurrently with biochemistry to address overcrowding of the curriculum. A careful design of the curriculum could also promote successful integration of biochemistry education to concepts relevant to professional roles because the relationship of biochemistry to other health-related subjects in one semester will be more explicit.

Authors of textbooks could use the results of the study. There is a need to design a textbook which is course-based, specific, and contextualized to the health sciences. Hence, the design of the textbook should promote critical thinking in biochemistry that is contextualized to the health sciences. Since pseudoscientific information are often masked as scientific in various educational media, such claims can be used as an assessment to scrutinize the ability of students to utilize critical thinking. These possible sources of discourses in biochemistry can be identified to promote the utilization of critical thinking in chemistry and its role in achieving health literacy.

The activities selected for chemical mereology-based instruction has the potential to address and correct misconceptions related to heuristic reasoning and inaccurate simplification of biochemistry concepts. Addressing misconceptions in biochemistry instruction should be highlighted and could be used to modify lifestyle-related decisions to maintain good health and promote chemistry-based health literacy to individuals, families and communities.

## Recommendations

It is recommended that mereology-based instruction be tried out in other chemistry subjects, such as general inorganic chemistry, organic chemistry and analytical chemistry in health science programs. In addition, related studies on other variables such as attitudes towards chemistry, self-efficacy and motivations also need to be assessed. Other learning characteristics such as visual-spatial ability and chemistry anxiety can also be assessed in relation to mereology-based instruction. This study affirms gender differences in all variables selected. However, it is assumed that the factors causing significant differences in ability logits may be more related to learning characteristics such as prior knowledge of chemistry concepts, prior knowledge of visual representations and pretest abilities in chemical identity thinking, critical thinking in chemistry and chemistry-based health literacy, not gender *per se*.

The research instruments such as chemical identity thinking instrument, critical thinking test in chemistry and chemistry-based health literacy test were multi-tiered instruments, making the evaluation of explanations arduous and time-consuming. Probably, a double tiered multiple-choice version of the tests can be developed using Rasch analysis. Alternative conceptions which were observed in this study can be used for distractor analysis. It is also possible to develop an online survey form for faster assessment and diagnosis of the level of chemistry-based health literacy that health science students possess prior to biochemistry instruction.

Mereology-based instruction can also be discussed in combination with a flipped classroom modality, where students learn part-whole relationship in online classes and implement their plans to prove or disprove part-whole relationships in actual laboratory classes.

A longitudinal study involving mereology-based instruction and chemistry-based health literacy can also be investigated to determine if the thinking process is also utilized long before the students complete their biochemistry subject. This would provide a basis whether chemistry-based health literacy indeed progresses over time as health science students progress towards completing health science subjects.

The implications of this study can be reviewed by Philippine institutions which offer health science programs to address the need to link biochemistry concepts to actual health outcomes by improving chemistry-based reasoning in health-related contexts such as maintenance of good health, disease prevention, cure, and rehabilitation.

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## Appendix A

### Item Content Validity of Prior Knowledge of Chemistry Concepts Test

| ITEM | E1 | E2 | E3 | E4 | E5 | $E_T$ | I-CVI | I-CVI Interpretation | pc | K | K Interpretation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0313 | 1.00 | Excellent |
| 2 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 3 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 4 | E | U | E | U | E | 3 | 0.6 | Eliminate | 0.0625 | 0.57 | Fair |
| 5 | E | U | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 6 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 7 | E | U | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 8 | E | E | E | - | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 9 | E | U | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 10 | E | U | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 11 | E | U | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 12 | E | U | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 13 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 14 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 15 | E | E | E | E | U | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 16 | U | U | E | E | E | 3 | 0.6 | Eliminate | 0.0625 | 0.57 | Fair |
| 17 | E | E | E | E | U | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 18 | E | E | E | U | U | 3 | 0.6 | Eliminate | 0.0625 | 0.57 | Fair |
| 19 | E | E | E | - | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 20 | E | U | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 21 | U | E | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 22 | E | E | E | E | U | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 23 | E | E | E | E | U | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 24 | E | U | E | - | E | 3 | 0.6 | Eliminate | 0.0625 | 0.57 | Fair |
| 25 | E | U | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 26 | E | U | E | E | U | 3 | 0.6 | Eliminate | 0.0625 | 0.57 | Fair |
| 27 | E | N | E | E | N | 3 | 0.6 | Eliminate | 0.0625 | 0.57 | Fair |
| 28 | E | E | E | E | NE | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 29 | N | - | E | - | U | 1 | 0.2 | Eliminate | 0.0313 | 0.17 | Discard |
| 30 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 31 | E | E | E | E | NE | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 32 | E | E | E | E | NE | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 33 | E | E | E | E | U | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 34 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 35 | E | E | E | E | NE | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 36 | N | E | E | E | U | 3 | 0.6 | Eliminate | 0.0625 | 0.57 | Fair |
| 37 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 38 | E | E | E | E | U | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 39 | E | N | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 40 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 41 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 42 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 43 | E | E | E | E | U | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 44 | E | U | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 45 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 46 | E | U | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 47 | E | U | E | E | E | 4 | 0.8 | Appropriate | 0.0313 | 0.79 | Excellent |
| 48 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 49 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 50 | E | U | E | E | U | 3 | 0.6 | Eliminate | 0.0625 | 0.57 | Fair |
| 51 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 52 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |
| 53 | E | U | E | E | U | 3 | 0.6 | Eliminate | 0.0625 | 0.57 | Fair |
| 54 | E | E | E | E | E | 5 | 1.0 | Appropriate | 0.0063 | 1.00 | Excellent |

# Appendix B

## Content Validity Rating of Prior Knowledge of Chemistry Concepts Test

| Item | Rating | | | | | | | | Interpretation |
|---|---|---|---|---|---|---|---|---|---|
| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $E_6$ | $E_7$ | Ave | |
| 1. The directions given are clear in all section of the data gathering instrument/ test. | 5 | 4 | 1 | 4 | 3 | 4 | 4 | 3.57 | Valid |
| 2. Each item is clearly stated. | 5 | 4 | 3 | 4 | 3 | 4 | 4 | 3.86 | Valid |
| 3. Each item is readable | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4.14 | Valid |
| 4. Each item is attractive to read; enough space is provided to avoid crowding among items. | 5 | 4 | 4 | 5 | 4 | 5 | 5 | 4.57 | Highly Valid |
| 5. The data gathering instrument is comprehensive; it covered all areas that are important in the study. | 5 | 5 | 3 | 5 | 4 | 5 | 5 | 4.57 | Highly Valid |
| 6. Each item is focused on a particular thought or idea. | 5 | 4 | 3 | 5 | 4 | 4 | 5 | 4.29 | Highly Valid |
| 7. The items are objective, i.e., the responses to be elicited are neither biased nor reactive. | 5 | 5 | 4 | 5 | 3 | 5 | 4 | 4.43 | Highly Valid |
| 8. The items are formulated in accordance to the explicit/ implicit objectives of the study. | 5 | 5 | 3 | 5 | 4 | 5 | 5 | 4.57 | Highly Valid |
| 9. The items are systematically arranged according to a desirable sequence. | 5 | 4 | 2 | 5 | 4 | 4 | 5 | 4.14 | Valid |
| 10. The items do not overlap with each other; no duplication of items is observed. | 5 | 5 | 1 | 5 | 4 | 4 | 4 | 4.00 | Valid |

# Appendix C

## Sample Letter for Pilot Testing

**SAINT LOUIS UNIVERSITY**
**School of Natural Sciences**
**Bonifacio St., Baguio City**

April 1, 2019

____________________
____________________
____________________

**Re: Pilot Testing of Research Instruments**

Dear Professor,

Greetings!

I am Jonathan M. Barcelo, a PhD Science Education (Chemistry major) candidate of the University of the Philippines Open University and a faculty member of School of Natural Sciences, Saint Louis University, Baguio City. Currently, I am conducting my dissertation on determining the effects of a mereology-based instruction on the chemical identity thinking, critical thinking and chemistry-based health literacy of health science students as part of the academic requirements of my PhD program.

Central to the concept of mereology is the determination of the relationship between a "part" and a "whole." This research is conducted under the supervision of my dissertation adviser, Dr. Marlene B. Ferido from University of Philippines National Institute of Mathematics and Science Education (UP-NISMED).

One of the activities in my research is the development and psychometric evaluation of research instruments such as Critical Thinking Test in Chemistry, Chemical Identity Thinking Instrument and Chemistry-based Health Literacy Test.

In relation to this, I am respectfully requesting your good office to allow me to administer the research instruments to a minimum of one hundred fifty first year medical laboratory science students who have completed inorganic and organic chemistry in__________. The details of the instruments and the proposed schedule is shown in Table 1.

Table 1. List of Instruments for Pilot Test

| Instrument | Number of Items | Minimum Number of Respondents | Time Required to Answer Instrument | Proposed Date of Pilot Tests |
|---|---|---|---|---|
| Critical Thinking Test in Chemistry | 26 | 150 | 50 to 60 minutes | April 11, 2019<br>April 25, 2019 |
| Chemistry-based Health Literacy Test | 28 | 150 | 60 to 70 minutes | April 12, 2019<br>April 26, 2019 |
| Chemical Identity Thinking Instrument | 20 | 150 | 50 to 60 minutes | April 13, 2019<br>April 27, 2019 |

The research protocol was approved by Saint Louis University Research Ethics Committee (SLU-REC). I have attached the approved research protocol, approval sheet and sample informed consent with this letter. The informed consent shall be obtained from the respondents prior to answering the instruments. Participation is entirely voluntary.

Rest assured that the information gathered in the study will be used for scholarly purposes only. Furthermore, all existing policies and guidelines related to the conduct of study in your institution will be strictly followed as required.

I am hoping for your positive approval for this academic endeavor. If there are concerns or comments, I may be reached via my e-mail address jmbarcelo@slu.edu.ph or through my contact number – 09153233044.

Thank you very much.

Respectfully yours,

**Jonathan M. Barcelo**
Saint Louis University
Baguio City

Noted:

**Marlene B. Ferido, PhD**
Research Adviser

# Appendix D

## Parameters of Rasch Analysis

| Parameter | Target Values | Remarks |
|---|---|---|
| Person Separation | ≥ 2.00 | Presence of two ability levels |
| Person Reliability | ≥ 0.80 | Ability level is reproducible |
| Item Separation | ≥ 3.00 | Presence of three item difficulty levels |
| Item Reliability | > 0.90 | Item difficulty are reproducible |
| Infit and Outfit MNSQ | MCQ: 0.70 to 1.30<br>PCM: 0.70 to 1.30<br>High stake: 0.80 to 1.20<br>Rating Scale: 0.60 to 1.40 | Indicates fitness of items to the Rasch model |
| Infit and Outfit ZTSD | -2.00 to 2.00 | Indicates fitness of items to the Rasch model |
| Point Measure Correlation | Should be positive | Ensures that all items contribute to the measurement of the latent variable or underlying construct |
| Unidimensionality<br>• Unexplained variance in first contrast<br>• PCA contrasts | ≤ 2 eigenvalues<br>1.00 | Unidimensionality and local independence indicates that the test is measuring one dimension only. |
| Differential Item Functioning | Mantel Haenszel statistics, $p<0.05$ indicates significant DIF<br>DIF Size:<br>Moderate to large<br>≥0.64 logit<br>Slight to moderate<br>≥ 0.43 logit<br>Negligible<br><0.43 logit | Significant DIF may indicate bias; items with significant DIF must be removed from list of items |

## Appendix E

### Details of Items in Prior Knowledge of Chemistry Concepts Test

| Item | Topic | Type | Remark | Decision | Final Item Number |
|---|---|---|---|---|---|
| Q01 | Measurement | Recall | GIC topic | Retained | Q01 |
| Q02 | Mole concept | Recall | GIC topic | Retained | Q02 |
| Q03 | Ionization | Analysis | GIC topic | Retained | Q03 |
| Q04 | Quantum number | Analysis | GIC topic | Retained | Q04 |
| Q05 | Atomic radius | Analysis | GIC topic | Retained | Q05 |
| Q06 | Balancing chemical equation | Application | GIC topic | Omitted* | - |
| Q07 | Malleability | Recall | GIC topic | Retained | Q06 |
| Q08 | Hydrogen bond | Recall | GIC topic | Retained | Q07 |
| Q09 | Vapor pressure | Analysis | GIC topic | Retained | Q08 |
| Q10 | Dialysis | Application | GIC topic | Retained | Q09 |
| Q11 | Boiling point | Analysis | GIC topic | Retained | Q10 |
| Q12 | Empirical formula | Recall | GIC topic | Retained | Q11 |
| Q13 | Mole Ratio | Evaluation | GIC topic | Retained | Q12 |
| Q14 | Stoichiometry | Application | GIC topic | Omitted | - |
| Q15 | Intermolecular force of attraction | Recall | GIC topic | Retained | Q13 |
| Q16 | Osmotic pressure | Application | GIC topic | Omitted* | - |
| Q17 | Chromatography | Analysis | GIC topic | Retained | Q14 |
| Q18 | Polarity | Evaluation | GIC topic | Retained | Q15 |
| Q19 | Density | Analysis | GIC topic | Retained | Q16 |
| Q20 | Conjugate-acid base | Recall | GIC topic | Retained | Q17 |
| Q21 | Buffer | Recall | GIC topic | Retained | Q18 |
| Q22 | Atomic property | Evaluation | GIC topic | Retained | Q19 |
| Q23 | Oxidation numbers | Evaluation | GIC topic | Retained | Q20 |
| Q24 | Stoichiometry | Application | GIC topic | Retained | Q21 |
| Q25 | Chemical Equilibrium | Analysis | GIC topic | Retained | Q22 |
| Q26 | Enthalpy | Application | TC topic | Omitted | - |
| Q27 | Hess Law | Analysis | TC topic | Retained | Q23 |
| Q28 | Hess Law | Analysis | TC topic | Retained | Q24 |
| Q29 | Reaction diagram | Recall | TC topic | Retained | Q25 |
| Q30 | Pi bond | Recall | GOC topic | Retained | Q26 |
| Q31 | Chemical formula | Recall | GOC topic | Retained | Q27 |
| Q32 | Nomenclature | Recall | GOC topic | Retained | Q28 |
| Q33 | Hybridization | Application | GOC topic | Retained | Q29 |
| Q34 | Bond strength | Analysis | GOC topic | Retained | Q30 |
| Q35 | Chirality | Recall | GOC topic | Retained | Q31 |
| Q36 | Isomerism | Recall | GOC topic | Retained | Q32 |
| Q37 | Boiling point | Analysis | GOC topic | Retained | Q33 |
| Q38 | Redox reaction | Recall | GOC topic | Retained | Q34 |
| Q39 | Resonance | Recall | GOC topic | Retained | Q35 |
| Q40 | Bromination | Application | GOC topic | Retained | Q36 |
| Q41 | Aromaticity | Analysis | GOC topic | Retained | Q37 |
| Q42 | Aromatic substituent | Analysis | GOC topic | Retained | Q38 |
| Q43 | Nucleophilic attack | Analysis | GOC topic | Retained | Q39 |
| Q44 | Alcohol reduction | Analysis | GOC topic | Retained | Q40 |
| Q45 | Oxidation of alcohol | Analysis | GOC topic | Retained | Q41 |
| Q46 | Reduction of ketone | Analysis | GOC topic | Retained | Q42 |
| Q47 | Nomenclature | Application | GOC topic | Omitted | - |
| Q48 | Carboxylic acid | Analysis | GOC topic | Retained | Q43 |
| Q49 | Acidity | Evaluation | GOC topic | Retained | Q44 |
| Q50 | Nucleophilic acyl substitution | Recall | GOC topic | Retained | Q45 |

Note: Items were reduced to 45 during pretest; Items with * indicate significant DIF by gender

# Appendix F

## Item Content Validity of Visual Representations Test

| ITEM | E1 | E2 | E3 | E4 | E5 | E6 | E7 | $E_T$ | I-CVI | I-CVI Interpretation | pc | K | Interpretation of K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | E | E | E | E | E | E | E | 7 | 1.000 | Appropriate | 0.0078 | 1.000 | Excellent |
| 2 | E | E | N | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 3 | E | E | N | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 4 | E | E | N | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 5 | E | E | U | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 6 | E | E | E | E | E | E | E | 7 | 1.000 | Appropriate | 0.0078 | 1.000 | Excellent |
| 7 | E | E | U | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 8 | E | E | E | E | E | E | E | 7 | 1.000 | Appropriate | 0.0078 | 1.000 | Excellent |
| 9 | E | E | E | E | E | E | E | 7 | 1.000 | Appropriate | 0.0078 | 1.000 | Excellent |
| 10 | U | E | U | E | E | E | U | 4 | 0.571 | Eliminate | 0.2734 | 0.410 | Fair |
| 11 | U | E | N | E | E | E | U | 7 | 1.000 | Appropriate | 0.0078 | 1.000 | Excellent |
| 12 | E | E | E | E | E | E | E | 7 | 1.000 | Appropriate | 0.0078 | 1.000 | Excellent |
| 13 | E | U | - | E | E | E | U | 5 | 0.714 | Revise | 0.1641 | 0.658 | Good |
| 14 | E | U | - | E | E | E | E | 5 | 0.714 | Revise | 0.1641 | 0.658 | Good |
| 15 | E | U | - | E | E | E | E | 5 | 0.714 | Revise | 0.1641 | 0.658 | Good |
| 16 | E | E | - | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 17 | E | E | - | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 18 | E | E | - | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 19 | E | E | - | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 20 | E | E | - | E | E | E | E | 7 | 1.000 | Appropriate | 0.0078 | 1.000 | Excellent |
| 21 | E | E | E | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 22 | E | E | U | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 23 | E | E | E | E | E | E | E | 7 | 1.000 | Appropriate | 0.0078 | 1.000 | Excellent |
| 24 | E | E | - | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |
| 25 | E | E | - | E | E | E | E | 6 | 0.857 | Appropriate | 0.0547 | 0.849 | Excellent |

## Appendix G

### Content Validity Rating of Visual Representations Test

| Item | Rating | | | | | | | Ave | Interpretation |
|---|---|---|---|---|---|---|---|---|---|
| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $E_6$ | $E_7$ | | |
| 1. The directions given are clear in all section of the data gathering instrument/ test. | 5 | 4 | 1 | 4 | 3 | 4 | 4 | 3.57 | Valid |
| 2. Each item is clearly stated. | 5 | 4 | 3 | 4 | 3 | 4 | 4 | 3.86 | Valid |
| 3. Each item is readable. | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4.14 | Valid |
| 4. Each item is attractive to read; enough space is provided to avoid crowding among items. | 5 | 4 | 4 | 5 | 4 | 5 | 5 | 4.57 | Highly Valid |
| 5. The data gathering instrument is comprehensive; it covered all areas that are important in the study. | 5 | 5 | 3 | 5 | 4 | 5 | 5 | 4.57 | Highly Valid |
| 6. Each item is focused on a particular thought or idea. | 5 | 4 | 3 | 5 | 4 | 4 | 5 | 4.29 | Highly Valid |
| 7. The items are objective, i.e., the responses to be elicited are neither biased nor reactive. | 5 | 5 | 4 | 5 | 3 | 5 | 4 | 4.43 | Highly Valid |
| 8. The items are formulated in accordance to the explicit/ implicit objectives of the study. | 5 | 5 | 3 | 5 | 4 | 5 | 5 | 4.57 | Highly Valid |
| 9. The items are systematically arranged according to a desirable sequence. | 5 | 4 | 2 | 5 | 4 | 4 | 5 | 4.14 | Valid |
| 10. The items do not overlap with each other; no duplication of items is observed. | 5 | 5 | 1 | 5 | 4 | 4 | 4 | 4.00 | Valid |

# Appendix H

## Details of Items in Visual Representations Test

| Item | Topic | Type | Visual Representation Type | Decision | Final Item Designation |
|---|---|---|---|---|---|
| Q01 | Atomic model | Analysis | PM | Retain | Q01 |
| Q02 | Representation of vaporization | Analysis | PM | Retain | Q02 |
| Q03 | Representation of boiling | Analysis | PM | Retain | Q03 |
| Q04 | Ion-dipole interaction | Analysis | PM | Retain | Q04 |
| Q05 | Determination of bond angle | Analysis | SM | Retain | Q05 |
| Q06 | Identification of hybridization of C | Analysis | SM | Retain | Q06 |
| Q07 | Identification of C in structure | Recall | SM | Retain | Q07 |
| Q08 | Identification of non-bonding electrons | Analysis | SM | Retain | Q08 |
| Q09 | Molecular geometry | Evaluation | SM | Retain | Q09 |
| Q10 | Heterocyclic aromatic ring | Analysis | SM | Retain | Q10 |
| Q11 | Molecular dipole | Analysis | SM | Retain | Q11 |
| Q12 | Molecular formula | Recall | SM | Retain | Q12 |
| Q13 | Determination of molecular orientation | Evaluation | SM | Retain | Q13 |
| Q14 | Determination of molecular orientation | Evaluation | SM | Retain | Q14 |
| Q15 | Molecular property | Analysis | SM | Omitted | - |
| Q16 | Determination of parts | Analysis | BSM | Retain | Q15 |
| Q17 | Molecular Property | Analysis | BSM | Retain | Q16 |
| Q18 | Functional group determination | Analysis | BSM | Retain | Q17 |
| Q19 | Determination of molecular formula | Analysis | BSM | Omitted | - |
| Q20 | Molecular property | Analysis | BSM | Retain | Q18 |
| Q21 | Molecular property | Analysis | EPM | Retain | Q19 |
| Q22 | Molecular property | Analysis | EPM | Retain | Q20 |
| Q23 | Molecular Property | Recall | EPM | Retain | Q21 |
| Q24 | Atomic orientation | Analysis | NP | Retain | Q22 |
| Q25 | Atomic orientation | Application | NP | Retain | Q23 |

PM=particle model, SM=skeletal model, BSM=ball and stick model, EPM=electrostatic potential map, NP= Newman Projection; Omitted items exhibited DIF by gender.

# Appendix I
## Item Content Validity of Chemical Identity Thinking Instrument

| ITEM | E1 | E2 | E3 | E4 | $E_T$ | I-CVI | I-CVI Interpretation | pc | k | Interpretation of k |
|---|---|---|---|---|---|---|---|---|---|---|
| Q01 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| Q02 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| Q03 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| Q04 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| Q05 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| Q06 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| Q07 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| Q08 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| Q09 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| Q10 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q01 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q02 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q03 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q04 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q05 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q06 | U | E | E | E | 3 | 0.75 | Revise | 0.125 | 0.714 | Good |
| q07 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q08 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q09 | E | E | E | E | 3 | 0.75 | Revise | 0.125 | 0.714 | Good |
| q10 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q11 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q12 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q13 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |
| q14 | E | E | E | E | 4 | 1.00 | Appropriate | 0.0625 | 1.000 | Excellent |

# Appendix J

## Content Validity Rating of Chemical Identity Thinking Instrument

| Item | Rating | | | | Ave | Interpretation |
|---|---|---|---|---|---|---|
| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | | |
| 1. The directions given are clear in all section of the data gathering instrument/ test. | 5 | 4 | 1 | 4 | 4.00 | Valid |
| 2. Each item is clearly stated. | 5 | 4 | 3 | 4 | 4.00 | Valid |
| 3. Each item is readable. | 5 | 4 | 4 | 4 | 4.50 | Valid |
| 4. Each item is attractive to read; enough space is provided to avoid crowding among items. | 5 | 4 | 4 | 5 | 4.25 | Highly Valid |
| 5. The data gathering instrument is comprehensive; it covered all areas that are important in the study. | 5 | 5 | 3 | 5 | 5.0 | Highly Valid |
| 6. Each item is focused on a particular thought or idea. | 5 | 4 | 3 | 5 | 4.25 | Highly Valid |
| 7. The items are objective, i.e., the responses to be elicited are neither biased nor reactive. | 5 | 5 | 4 | 5 | 4.50 | Highly Valid |
| 8. The items are formulated in accordance to the explicit/ implicit objectives of the study. | 5 | 5 | 3 | 5 | 4.50 | Highly Valid |
| 9. The items are systematically arranged according to a desirable sequence. | 5 | 4 | 2 | 5 | 4.25 | Valid |
| 10. The items do not overlap with each other; no duplication of items is observed. | 5 | 5 | 1 | 5 | 4.25 | Valid |

# Appendix K

## Details of Items in Chemical Identity Thinking Instrument

| Item | Topic | Classification | Remark |
|---|---|---|---|
| Q01 | Ethyl alcohol and rubbing alcohol | General Organic Chemistry | S vs M |
| Q02 | Fat and oil | Biochemistry | M vs M |
| Q03 | Starch and flour | Biochemistry | S vs M |
| Q04 | Albumin and egg white | Biochemistry | S vs M |
| Q05 | Butter and margarine | Biochemistry | M vs M |
| Q06 | Rubber and plastic | General Organic Chemistry | S vs S |
| Q07 | Dairy milk and soya milk | Biochemistry | M vs M |
| Q08 | Glass and fiber glass | General Inorganic Chemistry | M vs M |
| Q09 | Copper and glass | General Inorganic Chemistry | S vs M |
| Q10 | Aluminium and silver | General Inorganic Chemistry | S vs S |
| q01 | Amino acid and protein powder | Biochemistry | S vs S |
| q02 | Tryptophan and adenosine solution | Biochemistry | M vs M |
| q03 | Vitamin A in food and in creams | Biochemistry | M vs M |
| q04 | Aspartame and sugar sample | Biochemistry | S vs S |
| q05 | Boiled egg and scrambled egg | Biochemistry | M vs M |
| q06 | Nucleotide and Dietary nucleotide sample | Biochemistry | S vs M |
| q07 | Ethyl alcohol or acetic acid in wine | General Organic Chemistry | M vs M |
| q08 | Sucrose and lactose sample | Biochemistry | S vs S |
| q09 | Starch in pasta and in potatoes | Biochemistry | M vs M |
| q10 | Uncooked rice and steamed rice | Biochemistry | M vs M |

S = substance, M = mixture; All items were retained after pilot test. No items exhibited DIF by gender.

# Appendix L

## Item Content Validity of Critical Thinking Test in Chemistry

| Item | V1 | V2 | V3 | V4 | $V_E$ | I-CVI | I-CVI Interpretation | pc | K | Interpretation of K |
|---|---|---|---|---|---|---|---|---|---|---|
| Q01 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q02 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q03 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q04 | U | E | E | E | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q05 | E | E | U | E | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q06 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q07 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q08 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q09 | E | E | U | E | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q10 | E | E | U | E | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q11 | E | E | E | NE | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q12 | E | E | U | E | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q13 | E | E | U | E | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q14 | E | E | U | E | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q15 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q16 | E | E | U | U | 2 | 0.50 | Discard | 0.375 | 0.200 | Discard |
| Q17 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q18 | E | E | E | NE | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q19 | E | E | U | NE | 2 | 0.50 | Discard | 0.375 | 0.200 | Discard |
| Q20 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q21 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q22 | E | E | E | U | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q23 | E | U | E | NE | 2 | 0.50 | Discard | 0.375 | 0.200 | Discard |
| Q24 | E | E | E | U | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q25 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q26 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q27 | E | E | E | U | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q28 | E | E | E | U | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q29 | E | E | U | U | 2 | 0.50 | Discard | 0.375 | 0.200 | Discard |
| Q30 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| Q31 | E | E | U | E | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |
| Q32 | E | E | E | NE | 3 | 0.75 | Revise | 0.250 | 0.667 | Good |

# Appendix M

## Content Validity Rating of Critical Thinking Test in Chemistry

| Item | Rating | | | | Ave | Interpretation |
|---|---|---|---|---|---|---|
| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | | |
| 1. The directions given are clear in all section of the data gathering instrument/ test. | 5 | 4 | 3 | 4 | 4.00 | Valid |
| 2. Each item is clearly stated. | 4 | 4 | 3 | 2 | 3.25 | Moderately Valid |
| 3. Each item is readable. | 5 | 4 | 4 | 3 | 4.00 | Valid |
| 4. Each item is attractive to read; enough space is provided to avoid crowding among items. | 5 | 5 | 4 | 4 | 4.50 | Highly Valid |
| 5. The data gathering instrument is comprehensive; it covered all areas that are important in the study. | 5 | 5 | 3 | 4 | 4.25 | Highly Valid |
| 6. Each item is focused on a particular thought or idea. | 5 | 4 | 4 | 3 | 4.00 | Valid |
| 7. The items are objective, i.e., the responses to be elicited are neither biased nor reactive. | 5 | 5 | 3 | 3 | 4.00 | Valid |
| 8. The items are formulated in accordance to the explicit/ implicit objectives of the study. | 5 | 5 | 4 | 4 | 4.50 | Highly Valid |
| 9. The items are systematically arranged according to a desirable sequence. | 5 | 5 | 2 | 3 | 3.75 | Valid |
| 10. The items do not overlap with each other; no duplication of items is observed. | 5 | 5 | 1 | 4 | 3.75 | Valid |

# Appendix N

## Details of Items in Critical Thinking Test in Chemistry

| Item | Topic | Type | Decision | Final Item Designation |
|---|---|---|---|---|
| Q01 | Disproving misconception on OH⁻ vs -OH | GOC | Retained | Q01 |
| Q02 | Composition of vapor | LC | Retained | Q02 |
| Q03 | Understanding chemical equation | GIC | Retained | Q03 |
| Q04 | Molecular geometry and polarity | GOC | Retained | Q04 |
| Q05 | Metallic bonding | GIC | Retained | Q05 |
| Q06 | Azeotrope analysis | LC | Retained | Q06 |
| Q07 | Carboxylic acid and alkyl chain length | GOC | Retained | Q07 |
| Q08 | Electrolytes | LC | Retained | Q08 |
| Q09* | Colorimetric tests | LC | Omitted | - |
| Q10 | Bleach and disinfecting procedure | LC | Retained | Q09 |
| Q11 | Chromatographic analysis | LC | Retained | Q10 |
| Q12 | Strawberry juice analysis | LC | Retained | Q11 |
| Q13 | Protein and evaluation of acidity | GIC | Retained | Q12 |
| Q14 | Gas additives | GIC | Retained | Q13 |
| Q15* | Replacing acetic acid with phenol | GOC | Omitted | - |
| Q16 | Disproving misconception on H+ and acidity | GIC | Retained | Q14 |
| Q17 | Steric effect | LC | Retained | Q15 |
| Q18 | Chemical equilibrium in closed system | GOC | Retained | Q16 |
| Q19 | Silver chloride test | GOC | Retained | Q17 |
| Q20 | Evaluation of chemistry literature | LC | Retained | Q18 |

Omitted items exhibited DIF by gender.

# Appendix O

## Item Content Validity of Chemistry-based Health Literacy Test

| Item | $V_1$ | $V_2$ | $V_3$ | $V_4$ | $V_5$ | $V_E$ | I-CVI | I-CVI interpretation | pc | k | Interpretation of k |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | E | E | E | E | E | 5 | 1.00 | Appropriate | 0.031 | 1.000 | Excellent |
| 2 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 3 | E | E | E | E | E | 5 | 1.00 | Appropriate | 0.031 | 1.000 | Excellent |
| 4 | E | E | E | U | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 5 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 6 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 7 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 8 | - | E | E | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 9 | E | E | E | E | E | 5 | 1.00 | Revise | 0.031 | 1.000 | Excellent |
| 10 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 11 | E | E | E | E | E | 5 | 1.00 | Appropriate | 0.031 | 1.000 | Excellent |
| 12 | E | E | E | E | U | 4 | 0.80 | Appropriate | 0.156 | 0.763 | Excellent |
| 13 | E | E | E | E | E | 5 | 1.00 | Appropriate | 0.031 | 1.000 | Excellent |
| 14 | E | E | E | E | E | 5 | 1.00 | Appropriate | 0.031 | 1.000 | Excellent |
| 15 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 16 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 17 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 18 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 19 | E | E | U | U | E | 3 | 0.60 | Revise | 0.313 | 0.418 | Fair |
| 20 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 21 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 22 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 23 | E | E | E | E | E | 5 | 1.00 | Appropriate | 0.031 | 1.000 | Excellent |
| 24 | E | E | U | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 25 | E | E | N | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 26 | E | E | E | E | E | 5 | 1.00 | Revise | 0.031 | 1.000 | Excellent |
| 27 | E | E | N | E | E | 4 | 0.80 | Revise | 0.156 | 0.763 | Excellent |
| 28 | E | E | N | E | U | 3 | 0.60 | Revise | 0.313 | 0.418 | Fair |

# Appendix P

## Content Validity Rating of Chemistry-based Health Literacy Test

| Item | Rating | | | | | | Interpretation |
|---|---|---|---|---|---|---|---|
| | V1 | V2 | V3 | V4 | V5 | Ave | |
| 1. The directions given are clear in all section of the data gathering instrument/ test. | 5 | 5 | 4 | 4 | 5 | 4.60 | Highly Valid |
| 2. Each item is clearly stated. | 5 | 4 | 3 | 3 | 5 | 4.00 | Valid |
| 3. Each item is readable. | 5 | 5 | 3 | 4 | 5 | 4.40 | Highly Valid |
| 4. Each item is attractive to read; enough space is provided to avoid crowding among items. | 5 | 5 | 2 | 5 | 5 | 4.40 | Highly Valid |
| 5. The data gathering instrument is comprehensive; it covered all areas that are important in the study. | 5 | 5 | 3 | 5 | 5 | 4.60 | Highly Valid |
| 6. Each item is focused on a particular thought or idea. | 5 | 4 | 2 | 4 | 4 | 3.80 | Valid |
| 7. The items are objective, i.e., the responses to be elicited are neither biased nor reactive. | 5 | 4 | 3 | 5 | 5 | 4.40 | Highly Valid |
| 8. The items are formulated in accordance to the explicit/ implicit objectives of the study. | 5 | 5 | 3 | 4 | 5 | 4.40 | Highly Valid |
| 9. The items are systematically arranged according to a desirable sequence. | 5 | 5 | 2 | [illegible] | 4 | 4.00 | Valid |
| 10. The items do not overlap with each other; no duplication of items is observed. | 5 | 5 | 3 | 5 | 4 | 4.40 | Highly Valid |

# Appendix Q

## Details of Items in Chemistry-based Health Literacy Test

| Item | Topic | Type | Decision | Final Item Number |
|---|---|---|---|---|
| N1 | Frying oil and diet plan | Nutrition | Retained | N1 |
| P1 | Antibacterial drug and deactivation | Pharmacology | Retained | P1 |
| N2 | Milk product and heat-sensitive compound | Nutrition | Retained | NP1 |
| NP1 | Cytotoxic substance from seaweed | Natural Products | Omitted | - |
| N3 | Citrus-flavored noodle product | Nutrition | Retained | N2 |
| D1 | Urinalysis and metabolic disorder | Diagnostics | Omitted | - |
| NP2 | Vasodilatation in rats | Natural Products | Retained | NP2 |
| D2 | Food kit and sugar detection | Diagnostics | Retained | D1 |
| NP3 | Product containing oxidizable compound | Natural Products | Retained | NP3 |
| P2 | Fungal infection and antibacterial | Pharmacology | Retained | P2 |
| N4 | Compound R in fruits | Nutrition | Retained | N3 |
| D3 | Teeth staining and antibacterial drug | Diagnostics | Retained | D2 |
| N5 | Compound L in food | Nutrition | Omitted | - |
| N6 | Compound J and food preparation | Nutrition | Retained | N4 |
| D4 | Fecal analysis and GI bleeding | Diagnostics | Omitted | - |

Items which were omitted exhibited DIF (gender bias).

# Appendix R

## Item Content Validity of Cognitive Load Questionnaire

| Item | $V_1$ | $V_2$ | $V_3$ | $V_4$ | $V_E$ | I-CVI | I-CVI interpretation | pc | k | Interpretation of k |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 2 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 3 | E | E | E | N | 3 | 0.75 | Revise | 0.125 | 0.714 | Good |
| 4 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 5 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 6 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 7 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 8 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 9 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 10 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 11 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 12 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 13 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |
| 14 | E | E | E | E | 4 | 1.00 | Appropriate | 0.063 | 1.000 | Excellent |

# Appendix S

## Content Validity Rating of Cognitive Load Questionnaire

| Item | Rating |  |  |  | Ave | Interpretation |
|---|---|---|---|---|---|---|
|  | V1 | V2 | V3 | V4 |  |  |
| 1. The directions given are clear in all section of the data gathering instrument/ test. | 5 | 4 | 4 | 5 | 4.50 | Highly Valid |
| 2. Each item is clearly stated. | 5 | 3 | 5 | 4 | 4.25 | Valid |
| 3. Each item is readable. | 5 | 5 | 5 | 5 | 5.00 | Highly Valid |
| 4. Each item is attractive to read; enough space is provided to avoid crowding among items. | 5 | 5 | 4 | 5 | 4.75 | Highly Valid |
| 5. The data gathering instrument is comprehensive; it covered all areas that are important in the study. | 5 | 4 | 5 | 5 | 4.75 | Highly Valid |
| 6. Each item is focused on a particular thought or idea. | 5 | 3 | 5 | 4 | 4.25 | Valid |
| 7. The items are objective, i.e., the responses to be elicited are neither biased nor reactive. | 5 | 4 | 5 | 4 | 4.50 | Highly Valid |
| 8. The items are formulated in accordance to the explicit/ implicit objectives of the study. | 5 | 4 | 5 | 5 | 4.75 | Highly Valid |
| 9. The items are systematically arranged according to a desirable sequence. | 5 | 4 | 5 | 4 | 4.50 | Valid |
| 10. The items do not overlap with each other; no duplication of items is observed. | 5 | 3 | 4 | 4 | 4.00 | Highly Valid |

# Appendix T

## Details of Items in Cognitive Load Questionnaire

| Item | Topic | Type | Remark |
|---|---|---|---|
| Q01 | Difficulty of concept | ICL | |
| Q02 | Difficulty of topic | ICL | |
| Q03 | Unfamiliar terminologies | ECL-F | |
| Q04 | Visual representations | ECL-F | Coded in reverse |
| Q05 | Relationship of topic and visual representations | ECL-T | |
| Q06 | Instructions | ECL-F | Coded in reverse |
| Q07 | Conceptual evidences | ECL-T | |
| Q08 | Explaining concept in laboratory activity | ICL | Coded in reverse |
| Q09 | Relating chemical concepts to answers in questions | ECL-T | |
| Q10 | Support of visual representation to concept | ECL-T | Coded in reverse |
| Q11 | Mental effort in relating several chemical concepts | GCL | |
| Q12 | Confusion on chemical concepts when applied in the laboratory | GCL | |
| Q13 | Enhancement of understanding of laboratory concept using the theme | GCL | Coded in reverse |
| Q14 | Enhancement of understanding of topics using the theme | GCL | Coded in reverse |

ICL = intrinsic cognitive load; ECL-F = extraneous cognitive load on feature of activity; ECL-T = extraneous cognitive load related to task; GCL – germane cognitive load

# Appendix U

## Ethics Approval Sheet

SLU-REC Form 2.6

### APPROVAL CERTIFICATE

The following protocol, with its related documents, is approved for implementation by the Saint Louis University -Research Ethics Committee.

| Protocol No. | Principal Investigator |
|---|---|
| **SLU-REC 2019-021** | **Jonathan M. Barcelo** |

| | |
|---|---|
| Title | **Mereology-based Instruction: Effects on Chemical Identity Thinking, Critical Thinking and Chemistry-based Health Literacy** |

| | | | |
|---|---|---|---|
| Protocol Version/ Date | **2/March 13, 2019** | ICF Version/ Date | **2/March 13, 2019** |

| | | | |
|---|---|---|---|
| Type of review | ✓ Expedited<br>___ Full board<br>Meeting date:<br>**March 9, 2019 &**<br>**March 25, 2019** | Duration of Approval<br>**February 18, 2019 –**<br>**March 25, 2019** | Frequency of continuing review<br>**N/A** |

**Responsibilities of investigator/s after the protocol approval:**

- Seek approval from SLU-REC for any protocol/document amendment after this date
- Submit SAE and SUSAR reports to the REC within 7 days (see addendum next page)
- Submit progress report after/every ____ months
- Report protocol deviation/violation
- Abide by the principles of good clinical practice and ethical research
- Comply with all relevant international and national guidelines and regulations
- Submit final report after completion of study
- Others: ________________________________

For the SLU-REC

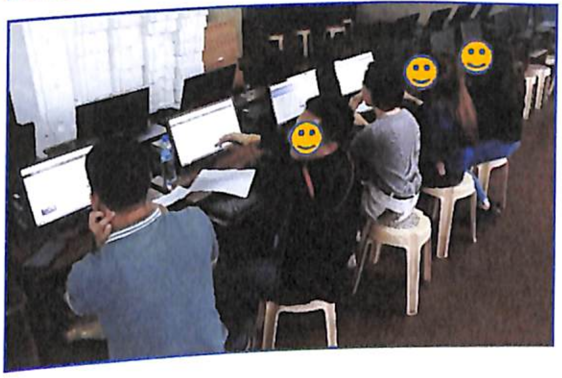
| REC Chairperson | Signature | Date |
|---|---|---|
| **ANA FE B. REVILLA** | | 25 March 2019 |

Received by:

| Principal Investigator | | Date |
|---|---|---|
| **JONATHAN M. BARCELO** | | 03/26/2019 |

# Appendix V

## Photo documentation of Workshop-Training of Biochemistry Instructors



# Appendix W

## Sample Informed Consent Form for Students

This informed consent form is for second year medical laboratory science students who will be invited to participate in the study **"Mereology-based Instruction: Effects on Chemical Identity Thinking, Critical Thinking and Chemistry-based Health Literacy."**

**Name of Principal Investigator:** Jonathan M. Barcelo
**Name of Institutional Affiliation:** Saint Louis University/ University of the Philippines Open University

The informed consent form has two parts:

- Informed Consent (to share information about the study with you)
- Certification of Consent (for signatures if you choose to participate)

You will be given a copy of the full informed consent form.

**PART 1: INFORMATION SHEET**

I am Jonathan M. Barcelo, a PhD Science Education (major in Chemistry) student of the University of the Philippines Open University, Los Banos, Laguna and a chemistry instructor of Saint Louis University, Baguio City. I am going to give you information and invite you to be a respondent of my study *Mereology-based Instruction: Effects on Chemical Identity Thinking, Critical Thinking and Chemistry-based Health Literacy*. This study is my dissertation for the program Doctor of Philosophy in Science Education (major in Chemistry).

This consent form may contain words that you may not understand. Please ask me to stop as we go through the information and I will be providing explanations. You may decide now or later if you are willing to participate in this study. You should read the information below and ask questions about anything you do not understand, before deciding whether or not to participate. You are being asked to participate in this study because you have satisfied the requirements to be a participant in the study.

**Purpose of the Study**

The main purpose of this study is to determine the effect of using a mereology-based instruction on chemical identity thinking, critical thinking and chemistry-based health literacy. Mereology refers to a "part-whole" relationship. In this study, I will be using teaching strategies in biochemistry which are based on "part-whole" relationship and investigate if it has an effect on your knowledge about the identity of a chemical concept, ability to use critical thinking in situations related to chemistry, and abilityto link chemistry concepts to health concepts. I hope to use what will be learned from study to contributeto the development of mereology-based instructional activities for biochemistry which is designed for health science programs such as BS Medical Laboratory Science.

**Participant Selection**

You are being invited as a participant in this study because you have completed inorganic and organic chemistry and you are currently enrolled in biochemistry. Since mereology-based instruction will be applied to biochemistry education for medical laboratory science students, the information which will be obtained from you is suitable for determining the effect of the mereology-based instruction.

**Voluntary Participation**

Your participation in this study is entirely voluntary. You have the right to refuse from participating in the study.

**Procedure**

If you volunteer to participate in this study, I will request you to take part in a fifteen-week activity which will cover workshops, initial data gathering, intervention phase (application of conventional or mereology-based instruction) and final data gathering. Out of the fifteen weeks, one week will be utilized to orient you on a) how to use online resources such as MolView, ChemDes and ChemMine, b) how to use Microsoft Excel, c) how to use basic statistical analysis for quantitative structure-activity relationship activities, and d) how to access learning materials in biochemistry. One week will be allotted for you to answer two diagnostic instruments – prior knowledge of chemistry concepts and prior knowledge of visual representations, and three pretest instruments – chemical identity thinking instrument, critical thinking test in chemistry, and chemistry-based health literacy test. Another week will be allotted during the final term for answering the posttest on chemical identity thinking instrument, critical thinking test in chemistry, and chemistry-based health literacy test. Your class will be randomly assigned to conventional instruction group or mereology-based instruction group.

The remaining twelve weeks will be involving the conventional or mereology-based activities in both Biochemistry lecture and laboratory class. These activities will include: (1) analysis of biochemistry literature, (2) attending an interview, if selected, to explain your answers in the research instruments; (3) performing computer-based (*in silico)* and hands-on quantitative structure-activity relationship laboratory activities; (4) submitting a laboratory report based on the quantitative structure-activity relationship activity; and, 5) answering arguments using a prescribed argumentation pattern. The main difference of conventional instruction group and mereology-based instruction group is the theme which are embedded in these activities. Conventional instruction is based on structure-property and structure-activity concept while mereology-based instruction is based on part-whole relationship. Central to part-whole relationship concept is the determination of properties or attributes of a part which is ascribable to a whole and vice versa. All the activities will be facilitated by your instructor in biochemistry whom I will be orienting regarding the study.

Please be informed that the duration of the mereology-based instruction is 12 weeks. Depending on the number of days without classes, the schedule will be moved as necessary to keep the duration of the schedule intact. Once you accept to be a part of either mereology-based instruction group or conventional instruction group, you will be assigned with an identification code for anonymity. You will also be provided with an institutional ID and password to gain access to learning materials corresponding to the group that you are assigned to.

**Potential Risks and Discomfort**

Inconveniences will be minor and are not likely to happen. In addition, the inconveniences are all related to academic activities. Some inconveniences may be related to anxiousness or tiredness while answering different tests or instruments. The laboratory activities related to QSAR activities may have some reagents which are potentially hazardous. However, the activity will involve micro-scale quantities to minimize risks related to exposure in the laboratory. This means that the reagents to be used in the laboratory activities will be performed using very small amount of chemicals. in addition, your laboratory teacher will orient you regarding safety measures and the importance of personal protective equipment in the laboratory. Lastly, your teacher will be orienting you with the risks associated with the activity in the laboratory and review proper laboratory techniques and protocols to ensure safety in the biochemistry laboratory class. The use of personal protective equipment will be oriented at the start of each activity.

**Benefits**

It is not likely that you will benefit directly from participation in this study, but the conventional instruction and mereology-based instruction materials can be used in learning biochemistry concepts prior to learning clinical chemistry.

**Compensation for Participation**

You will not receive any payment or other compensation for participation in this study. There is also no cost to you for participation. Your participation will not be a basis for passing your Biochemistry subject as well. Regardless of which group you will be assigned, the retention policy for the program will still be followed.

**Confidentiality**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Confidentiality will be maintained by means of a instruction group-block number-student-number (example: MBI-01-01 or CI-01-01). Your name will not be used in any of the information that will be reported in any research forum or publication. When the study is finished, the list that shows which code number goes with your name will be kept in a locker. Information that can identify you individually will not be released to anyone outside the study.

**Sharing of Results**

I may use any information that we get from this study in any way I think is best for publication or education. Any information which will be used for publication or presentation will not identify you individually. The name of the institution will be kept confidential as well.

**Participation and Right to Refuse**

You can choose whether or not to be in this study. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. There is no penalty if you withdraw from the study and you will not lose any benefits to which you are otherwise entitled. In addition, the information you will provide will not affect your grades in your enrolled subjects. Your responses will not affect the reputation of your department or school, since all information will be held confidential and will be presented in a summary form only.

**Who to Contact:**

If you have any questions or concerns about the research, please feel free to contact:

**Jonathan M. Barcelo**
Principal Investigator
School of Natural Sciences
Saint Louis University, Baguio City
09153233044
E-mail: jmbarcelo@slu.edu.ph

**Rights of Participants**

The Saint Louis University Research Ethics Committee (SLU REC) has reviewed my request to conduct this study. This study has been assigned with the approval number **SLU-REC 2019-021** last March 25, 2019. If you have any concerns about your rights in this study, please contact the following members of the SLU REC.

**Anna Fe B. Revilla, RPh, MSc**
Chairman, Research Ethics Committee
Saint Louis University, Baguio City
09228125474
Tel: (074) 444-8246 to 48 local 339

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

**Printed Name of Participant**

**Signature of the Participant**

**Date Signed:** ____________________

**Date Signed:** ____________________

**Attested by:** ____________________
**Name and Signature**

# Appendix X

## Sample Statistical Analysis Results

## Analysis of Covariance

### *Chemical Identity Thinking*

**Tests of Between-Subjects Effects**

Dependent Variable: CITI posttest logit

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 17.948[a] | 4 | 4.487 | 20.817 | .000 | 127 |
| Intercept | 1.278 | 1 | 1.278 | 5.928 | .015 | .010 |
| pkcctlogit | 12.098 | 1 | 12.098 | 56.128 | .000 | .089 |
| gender | 3.581 | 3 | 1.194 | 5.537 | .001 | .028 |
| Error | 123.291 | 572 | .216 | | | |
| Total | 141.548 | 577 | | | | |
| Corrected Total | 141.239 | 576 | | | | |

a. R Squared = .127 (Adjusted R Squared = .121)

**Tests of Between-Subjects Effects**

Dependent Variable: CITI posttest logit

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 9.003[a] | 4 | 2.251 | 9.736 | .000 | .064 |
| Intercept | 1.363 | 1 | 1.363 | 5.896 | .015 | .010 |
| vrtlogit | 3.153 | 1 | 3.153 | 13.639 | .000 | .023 |
| gender | 4.356 | 3 | 1.452 | 6.281 | .000 | .032 |
| Error | 132.238 | 572 | .231 | | | |
| Total | 141.548 | 577 | | | | |
| Corrected Total | 141.239 | 576 | | | | |

a. R Squared = .064 (Adjusted R Squared = .057)

**Tests of Between-Subjects Effects**

Dependent Variable: CITI posttest logit

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 20.880[a] | 4 | 5.215 | 24.779 | .000 | .148 |
| Intercept | 6.639 | 1 | 6.639 | 31.544 | .000 | .052 |
| citiprelogit | 15.009 | 1 | 15.009 | 71.319 | .000 | .111 |
| gender | 4.712 | 3 | 1.571 | 7.464 | .000 | .038 |
| Error | 120.380 | 572 | .210 | | | |
| Total | 141.548 | 577 | | | | |
| Corrected Total | 141.239 | 576 | | | | |

a. R Squared = .148 (Adjusted R Squared = .142)

## Analysis of Covariance

### *Critical Thinking in Chemistry*

**Tests of Between-Subjects Effects**

Dependent Variable: CTTC posttest logit

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 41.879$^a$ | 4 | 10.470 | 42.184 | .000 | .228 |
| Intercept | 70.798 | 1 | 70.798 | 285.320 | .000 | .333 |
| pkcctlogit | 26.440 | 1 | 26.440 | 106.555 | .000 | .157 |
| gender | 9.670 | 3 | 3.223 | 12.990 | .000 | .064 |
| Error | 141.934 | 572 | .248 | | | |
| Total | 378.264 | 577 | | | | |
| Corrected Total | 183.813 | 576 | | | | |

a. R Squared = .228 (Adjusted R Squared = .222)

**Tests of Between-Subjects Effects**

Dependent Variable: CTTC posttest logit

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 35.931$^a$ | 4 | 8.983 | 34.744 | .000 | .195 |
| Intercept | 60.042 | 1 | 60.042 | 232.240 | .000 | .289 |
| vrtlogit | 20.491 | 1 | 20.491 | 79.259 | .000 | .122 |
| gender | 8.930 | 3 | 2.977 | 11.513 | .000 | .057 |
| Error | 147.882 | 572 | .259 | | | |
| Total | 378.264 | 577 | | | | |
| Corrected Total | 183.813 | 576 | | | | |

a. R Squared = .195 (Adjusted R Squared = .190)

**Tests of Between-Subjects Effects**

Dependent Variable: CTTC posttest logit

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 52.119$^a$ | 4 | 13.030 | 56.593 | .000 | .284 |
| Intercept | .200 | 1 | .200 | .871 | .351 | .002 |
| cttcprelogit | 36.679 | 1 | 36.679 | 159.313 | .000 | .218 |
| gender | 9.227 | 3 | 3.076 | 13.359 | .000 | .065 |
| Error | 131.694 | 572 | .230 | | | |
| Total | 378.264 | 577 | | | | |
| Corrected Total | 183.813 | 576 | | | | |

a. R Squared = .284 (Adjusted R Squared = .279)

# Analysis of Covariance

## Chemistry-based Health Literacy Test

### Tests of Between-Subjects Effects

Dependent Variable: CBHLT posttest logit

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 48.720[a] | 4 | 12.180 | 36.301 | .000 | .202 |
| Intercept | 2.435 | 1 | 2.435 | 7.257 | .007 | .013 |
| pkcctlogit | 12.024 | 1 | 12.024 | 35.836 | .000 | .059 |
| gender | 33.269 | 3 | 11.090 | 33.052 | .000 | .148 |
| Error | 191.919 | 572 | .338 | | | |
| Total | 256.821 | 577 | | | | |
| Corrected Total | 240.838 | 576 | | | | |

a. R Squared = .202 (Adjusted R Squared = .197)

### Tests of Between-Subjects Effects

Dependent Variable: CBHLT posttest logit

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 44.361[a] | 4 | 11.090 | 32.320 | .000 | .184 |
| Intercept | 1.571 | 1 | 1.571 | 4.580 | .033 | .008 |
| vrtlogit | 7.665 | 1 | 7.665 | 22.337 | .000 | .038 |
| gender | 33.140 | 3 | 11.047 | 32.193 | .000 | .144 |
| Error | 196.277 | 572 | .343 | | | |
| Total | 256.821 | 577 | | | | |
| Corrected Total | 240.638 | 576 | | | | |

a. R Squared = .184 (Adjusted R Squared = .179)

### Tests of Between-Subjects Effects

Dependent Variable: CBHLT posttest logit

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 78.184[a] | 4 | 19.546 | 68.821 | .000 | .325 |
| Intercept | 7.132 | 1 | 7.132 | 25.110 | .000 | .042 |
| cbhltprelogit | 41.488 | 1 | 41.488 | 146.077 | .000 | .203 |
| gender | 33.061 | 3 | 11.020 | 38.802 | .000 | .169 |
| Error | 162.455 | 572 | .284 | | | |
| Total | 256.821 | 577 | | | | |
| Corrected Total | 240.638 | 576 | | | | |

a. R Squared = .325 (Adjusted R Squared = .320)

## Analysis of Covariance of Rasch Learning Gains

### *Chemical Identity Thinking*

**Tests of Between-Subjects Effects**

Dependent Variable: citiraschgain

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 4.749$^a$ | 4 | 1.187 | 3.322 | .011 | .023 |
| Intercept | 65.108 | 1 | 65.108 | 182.158 | .000 | .242 |
| pkcctlogit | .510 | 1 | .510 | 1.426 | .233 | .002 |
| gender | 4.038 | 3 | 1.346 | 3.766 | .011 | .019 |
| Error | 204.450 | 572 | .357 | | | |
| Total | 304.950 | 577 | | | | |
| Corrected Total | 209.199 | 576 | | | | |

a. R Squared = .023 (Adjusted R Squared = .016)

### *Critical Thi*

**Tests of Between-Subjects Effects**

Dependent Variable: citiraschgain

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 4.250$^a$ | 4 | 1.063 | 2.965 | .019 | .020 |
| Intercept | 61.895 | 1 | 61.695 | 172.746 | .000 | .232 |
| vrtlogit | .011 | 1 | .011 | .030 | .862 | .000 |
| gender | 4.182 | 3 | 1.394 | 3.891 | .009 | .020 |
| Error | 204.949 | 572 | .358 | | | |
| Total | 304.950 | 577 | | | | |

### *Chemistry-b*

**Tests of Between-Subjects Effects**

Dependent Variable: citiraschgain

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 88.819$^a$ | 4 | 22.205 | 105.509 | .000 | .425 |
| Intercept | 6.639 | 1 | 6.639 | 31.544 | .000 | .052 |
| citiprelogit | 84.580 | 1 | 84.580 | 401.893 | .000 | .413 |
| gender | 4.712 | 3 | 1.571 | 7.464 | .000 | .038 |
| Error | 120.380 | 572 | .210 | | | |
| Total | 304.950 | 577 | | | | |
| Corrected Total | 209.199 | 576 | | | | |

a. R Squared = .425 (Adjusted R Squared = .421)

## Multiple Linear Regression

### *Chemical Identity Thinking, Mereology-based Instruction Group*

**Model Summary**[b]

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson |
|---|---|---|---|---|---|
| 1 | .478[a] | .229 | .218 | .507752 | 1.479 |

a. Predictors: (Constant), gender, CITI pretest logit, VRT logit, PKCCT logit

b. Dependent Variable: CITI posttest logit

**ANOVA**[a]

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 21.800 | 4 | 5.450 | 21.139 | .000[b] |
| | Residual | 73.476 | 285 | .258 | | |
| | Total | 95.276 | 289 | | | |

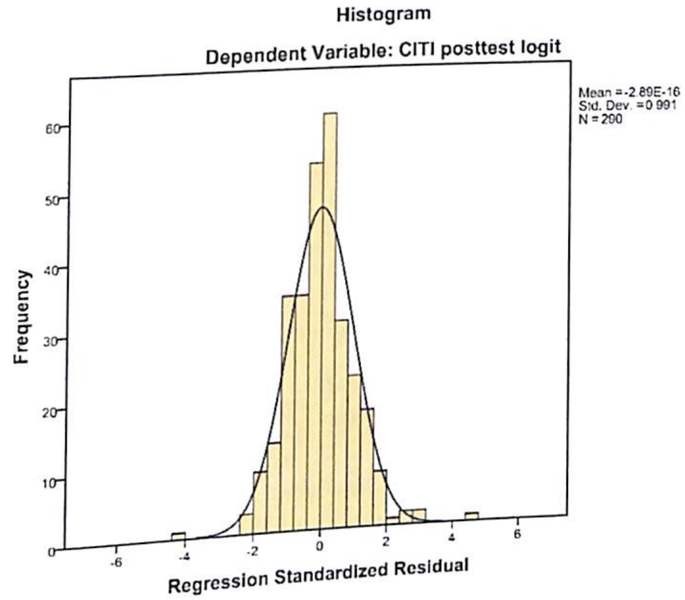
a. Dependent Variable: CITI posttest logit

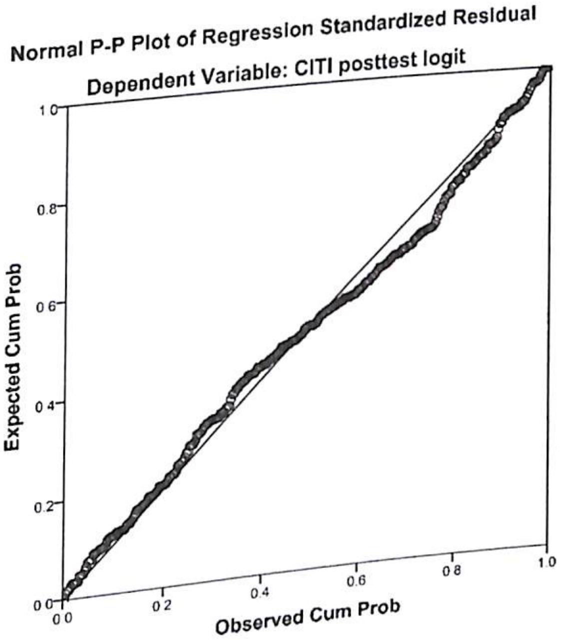
b. Predictors: (Constant), gender, CITI pretest logit, VRT logit, PKCCT logit

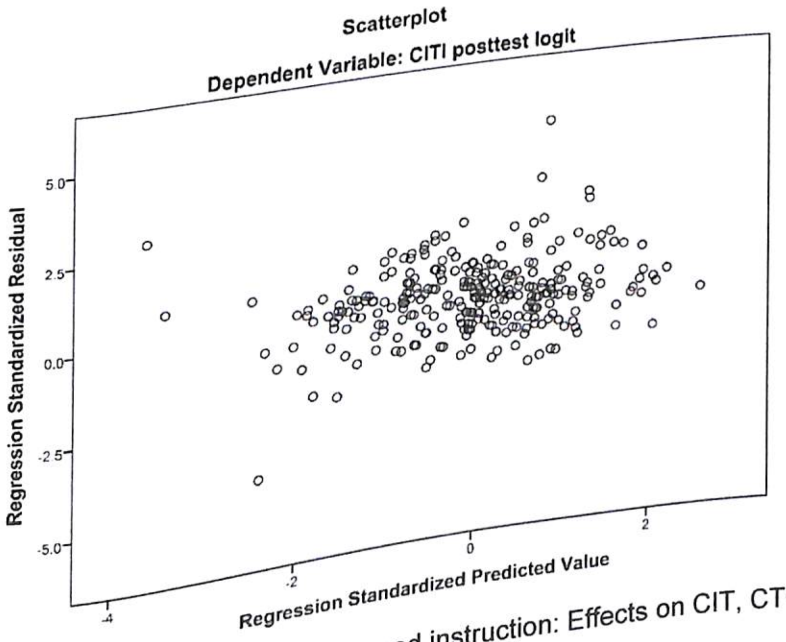
**Coefficients**[a]

| Model | | 95.0% Confidence Interval for B | | Collinearity Statistics | | Sig. |
|---|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Tolerance | VIF | |
| 1 | (Constant) | .298 | .893 | | | .000 |
| | PKCCT logit | .172 | .469 | .735 | 1.381 | .000 |
| | VRT logit | -.132 | .062 | .755 | 1.325 | .480 |
| | CITI pretest logit | .204 | .427 | .923 | 1.083 | .000 |
| | gender | -.387 | -.064 | .943 | 1.061 | .006 |

a. Dependent Variable: CITI posttest logit


Histogram
Dependent Variable: CITI posttest logit
Mean =-2.89E-16
Std. Dev. =0.991
N=290
Frequency
0
10
20
30
40
50
60
-6
-4
-2
0
2
4
6
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: CITI posttest logit
Expected Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0


Scatterplot
Dependent Variable: CITI posttest logit
Regression Standardized Residual
5.0
2.5
0.0
-2.5
-5.0
-4
-2
0
2
Regression Standardized Predicted Value

## *Chemical Identity Thinking, Conventional Instruction Group*

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .400[a] | .160 | .148 | .367088 |

a. Predictors: (Constant), gender, CITI pretest logit , VRT logit , PKCCT logit

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 7.226 | 4 | 1.807 | 13.406 | .000[b] |
| | Residual | 38.001 | 282 | .135 | | |
| | Total | 45.227 | 286 | | | |

a. Dependent Variable: CITI posttest logit

b. Predictors: (Constant), gender, CITI pretest logit , VRT logit , PKCCT logit

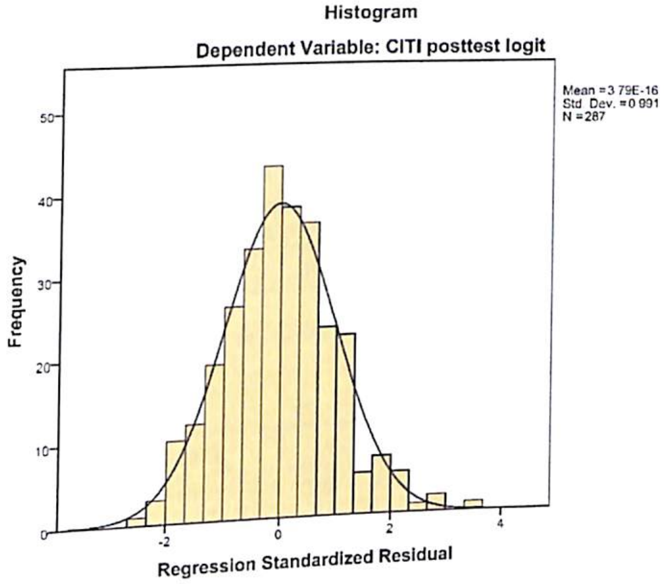
**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .038 | .095 | | .401 | .688 |
| | PKCCT logit | .181 | .053 | .207 | 3 429 | .001 |
| | VRT logit | .060 | .038 | .097 | 1.601 | .110 |
| | CITI pretest logit | .187 | .040 | .258 | 4.631 | 000 |
| | gender | .010 | .053 | .011 | .194 | .847 |

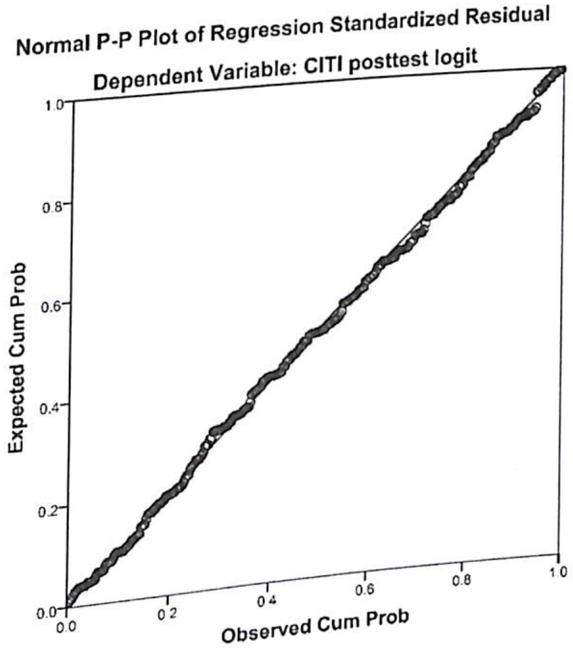
**Coefficients[a]**

| Model | | 95.0% Confidence Interval for B | | Collinearity Statistics | |
|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Tolerance | VIF |
| 1 | (Constant) | -.149 | .225 | | |
| | PKCCT logit | .077 | .284 | .816 | 1.225 |
| | VRT logit | -.014 | .135 | .819 | 1.220 |
| | CITI pretest logit | .103 | .267 | .957 | 1.045 |
| | gender | -.094 | .115 | .952 | 1.050 |

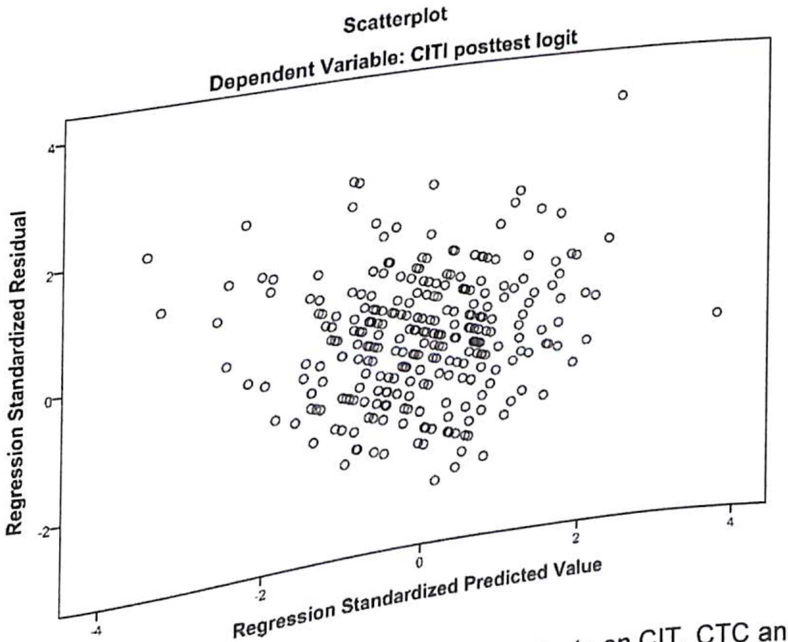
a. Dependent Variable: CITI posttest logit


Histogram

Dependent Variable: CITI posttest logit


Normal P-P Plot of Regression Standardized Residual

Dependent Variable: CITI posttest logit


Scatterplot

Dependent Variable: CITI posttest logit

*Critical Thinking in Chemistry, Mereology-based Instruction Group*

**Model Summary**[b]

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson |
|---|---|---|---|---|---|
| 1 | .604[a] | .364 | .355 | .462350 | 1.483 |

**ANOVA**[a]

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 34.911 | 4 | 8.728 | 40.828 | .000[b] |
| | Residual | 60.924 | 285 | .214 | | |
| | Total | 95.835 | 289 | | | |

a. Dependent Variable: CTTC posttest logit

b. Predictors: (Constant), gender, PKCCT logit , CTTC pretest logit , VRT logit

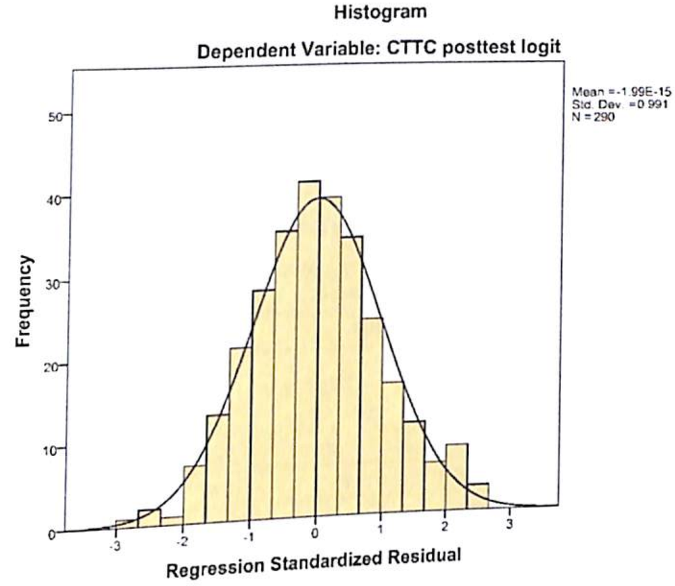
**Coefficients**[a]

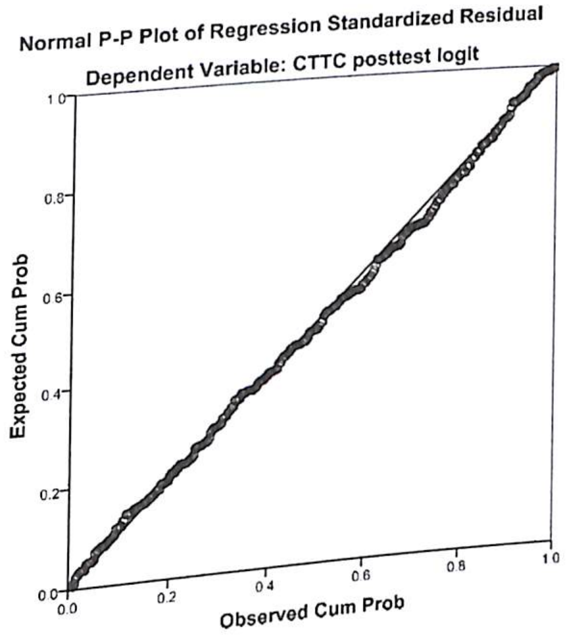
| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .229 | .141 | | 1.625 | .105 |
| | PKCCT logit | .165 | .072 | .132 | 2.289 | .023 |
| | VRT logit | .134 | .045 | .162 | 2.955 | .003 |
| | CTTC pretest logit | .512 | .067 | .415 | 7.651 | .000 |
| | gender | -.130 | .075 | -.085 | -1.724 | .086 |

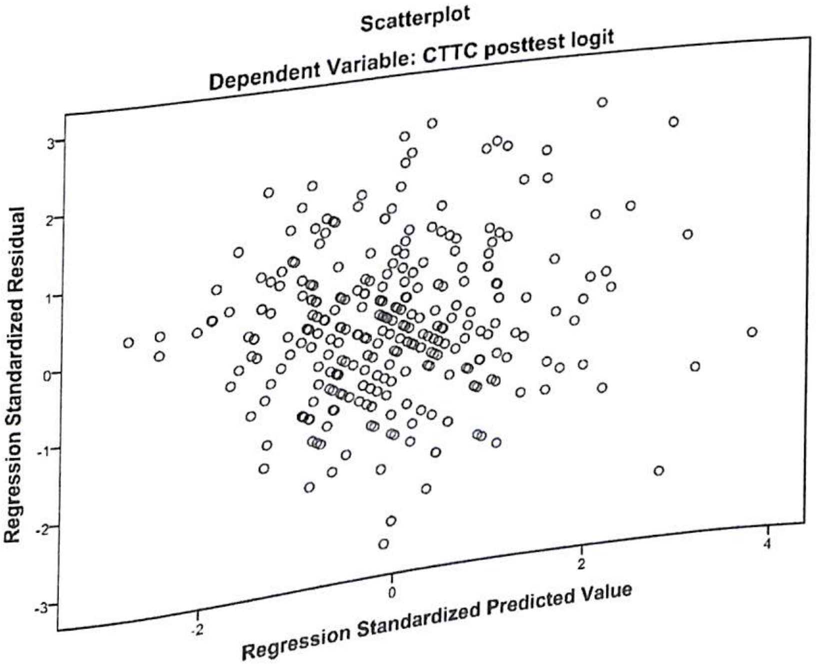
**Coefficients**[a]

| Model | | 95.0% Confidence Interval for B | | Collinearity Statistics | |
|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Tolerance | VIF |
| 1 | (Constant) | -.048 | .506 | | |
| | PKCCT logit | .023 | .306 | .674 | 1.484 |
| | VRT logit | .045 | .222 | .744 | 1.345 |
| | CTTC pretest logit | .380 | .644 | .758 | 1.319 |
| | gender | -.278 | .018 | .926 | 1.080 |

a. Dependent Variable: CTTC posttest logit


Histogram
Dependent Variable: CTTC posttest logit
Mean =-1.99E-15
Std. Dev. =0.991
N = 290
Frequency
50
40
30
20
10
0
-3
-2
-1
0
1
2
3
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: CTTC posttest logit
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob


Scatterplot
Dependent Variable: CTTC posttest logit
Regression Standardized Residual
3
2
1
0
-1
-2
-3
-2
0
2
4
Regression Standardized Predicted Value

## *Critical Thinking in Chemistry, Conventional Instruction Group*

### Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .562$^a$ | .316 | .306 | .452401 |

### ANOVA$^a$

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 26.614 | 4 | 6.654 | 32.509 | .000$^b$ |
| | Residual | 57.716 | 282 | .205 | | |
| | Total | 84.330 | 286 | | | |

a. Dependent Variable: CTTC posttest logit

b. Predictors: (Constant), gender, PKCCT logit , VRT logit , CTTC pretest logit

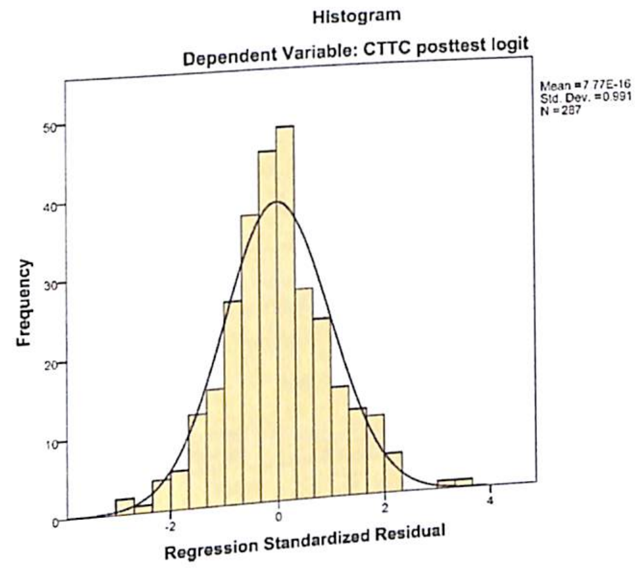
### Coefficients$^a$

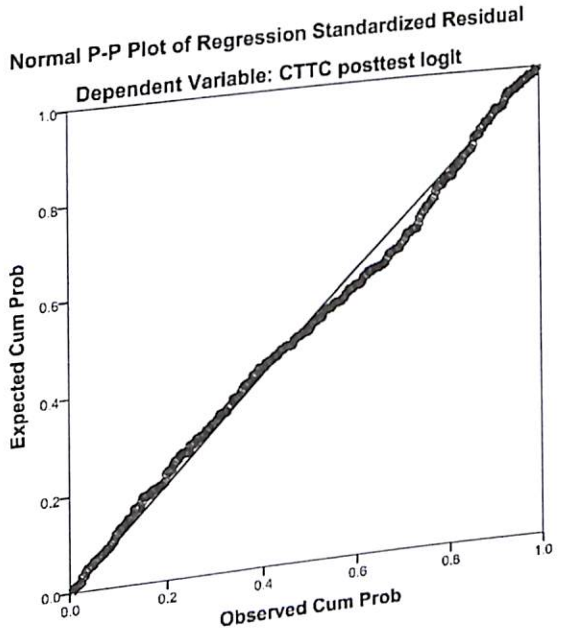
| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .016 | .121 | | .133 | .894 |
| | PKCCT logit | .280 | .067 | .235 | 4.157 | .000 |
| | VRT logit | .145 | .047 | .170 | 3.065 | .002 |
| | CTTC pretest logit | .309 | .070 | .249 | 4.424 | .000 |
| | gender | -.195 | .066 | -.151 | -2.958 | .003 |

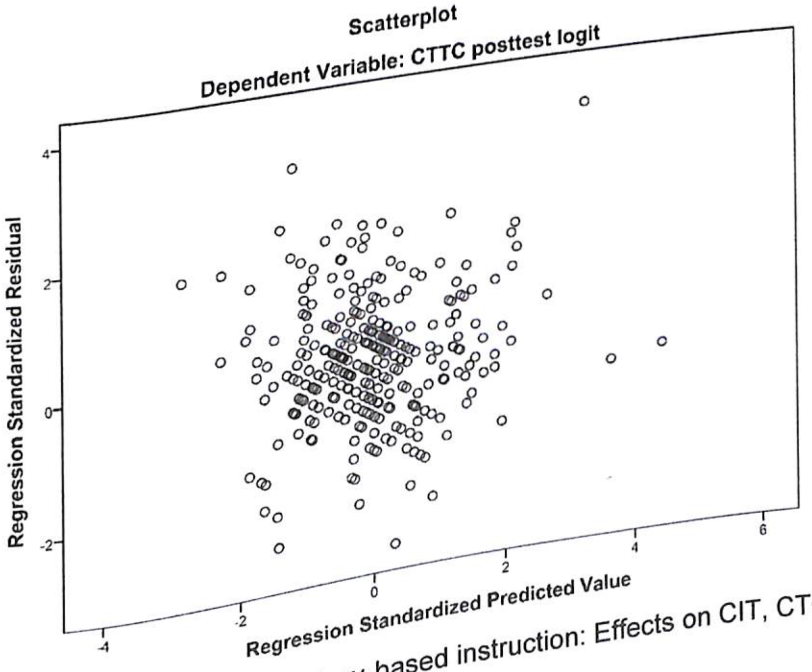
### Coefficients$^a$

| Model | | 95.0% Confidence Interval for B | | Collinearity Statistics | |
|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Tolerance | VIF |
| 1 | (Constant) | -.222 | .254 | | |
| | PKCCT logit | .148 | .413 | .756 | 1.322 |
| | VRT logit | .052 | .239 | .788 | 1.270 |
| | CTTC pretest logit | .171 | .448 | .768 | 1.301 |
| | gender | -.328 | -.065 | .932 | 1.073 |

a. Dependent Variable: CTTC posttest logit


Histogram
Dependent Variable: CTTC posttest logit
Mean =7.77E-16
Std. Dev. =0.991
N =287
Frequency
50
40
30
20
10
0
-2
0
2
4
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: CTTC posttest logit
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob


Scatterplot
Dependent Variable: CTTC posttest logit
Regression Standardized Residual
4
2
0
-2
-4
-2
0
2
4
6
Regression Standardized Predicted Value

### Model Summary[b]

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson |
|---|---|---|---|---|---|
| 1 | .486[a] | .236 | .228 | .583293 | 1.571 |

a. Predictors: (Constant), gender, CBHLT pretest logit, VRT logit , PKCCT logit

b Dependent Variable: CBHLT posttest logit

### ANOVA[a]

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 30.001 | 4 | 7.500 | 22.045 | .000[b] |
| | Residual | 96.966 | 285 | .340 | | |
| | Total | 126.967 | 289 | | | |

a. Dependent Variable: CBHLT posttest logit

b. Predictors: (Constant), gender, CBHLT pretest logit, VRT logit , PKCCT logit

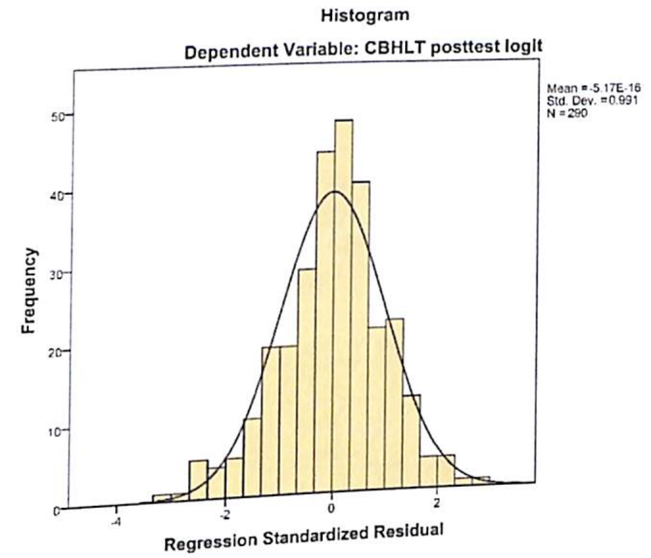
### Coefficients[a]

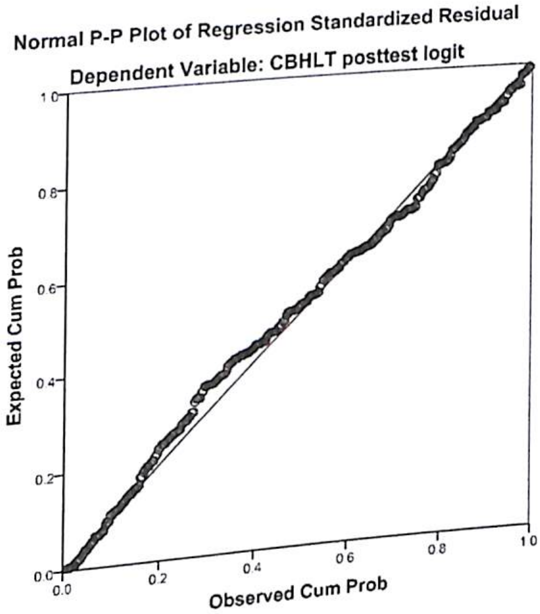
| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .800 | .175 | | 4.570 | .000 |
| | PKCCT logit | .131 | .086 | .091 | 1.521 | .129 |
| | VRT logit | .113 | .057 | .119 | 1.999 | .047 |
| | CBHLT pretest logit | .461 | .062 | .389 | 7.389 | .000 |
| | gender | -.225 | .094 | -.127 | -2.392 | .017 |

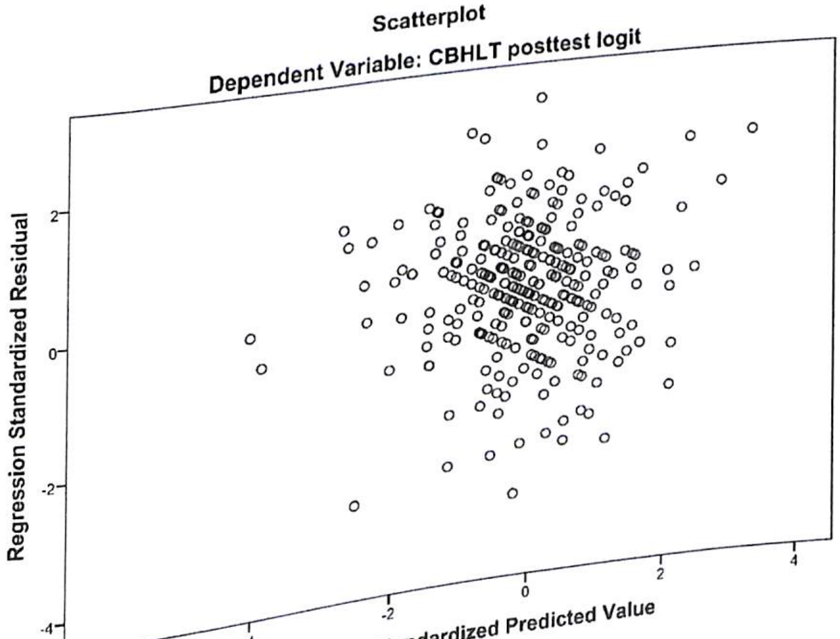
### Coefficients[a]

| Model | | 95.0% Confidence Interval for B | | Collinearity Statistics | |
|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Tolerance | VIF |
| 1 | (Constant) | .455 | 1.145 | | |
| | PKCCT logit | -.039 | .301 | .744 | 1.345 |
| | VRT logit | .002 | .224 | .757 | 1.321 |
| | CBHLT pretest logit | .338 | .583 | .969 | 1.032 |
| | gender | -.410 | -.040 | .946 | 1.057 |

a. Dependent Variable: CBHLT posttest logit


Histogram
Dependent Variable: CBHLT posttest logit
Mean = -5.17E-16
Std. Dev. = 0.991
N = 290
Frequency
50
40
30
20
10
0
-4
-2
0
2
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: CBHLT posttest logit
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob


Scatterplot
Dependent Variable: CBHLT posttest logit
Regression Standardized Residual
2
0
-2
-4
-6
-4
-2
0
2
4
Regression Standardized Predicted Value

*Chemistry-based Health Literacy, Conventional Instruction Group*

### Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .542[a] | .294 | .284 | .454199 |

### ANOVA[a]

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 24.174 | 4 | 6.044 | 29.295 | .000[b] |
| | Residual | 58.176 | 282 | .206 | | |
| | Total | 82.350 | 286 | | | |

a. Dependent Variable: CBHLT posttest logit

b. Predictors: (Constant), gender, CBHLT pretest logit, PKCCT logit , VRT logit

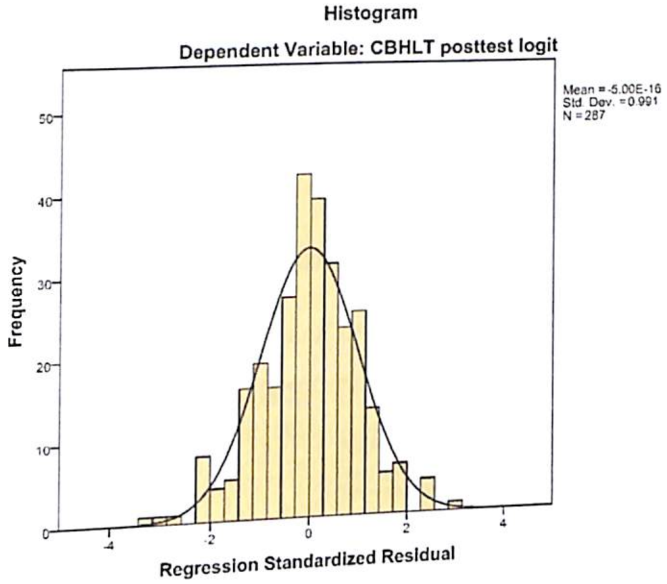
### Coefficients[a]

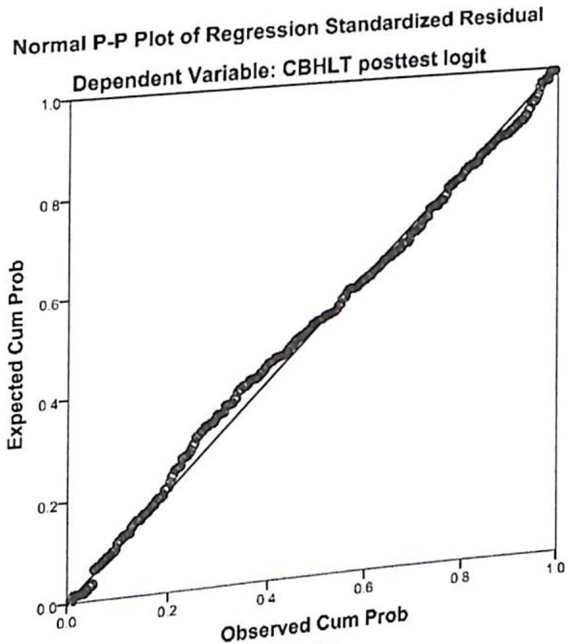
| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -.136 | .119 | | -1.139 | .256 |
| | PKCCT logit | .211 | .065 | .179 | 3.254 | .001 |
| | VRT logit | .052 | .047 | .061 | 1.096 | .274 |
| | CBHLT pretest logit | .439 | .050 | .455 | 8.810 | .000 |
| | gender | .033 | .066 | .026 | .498 | .619 |

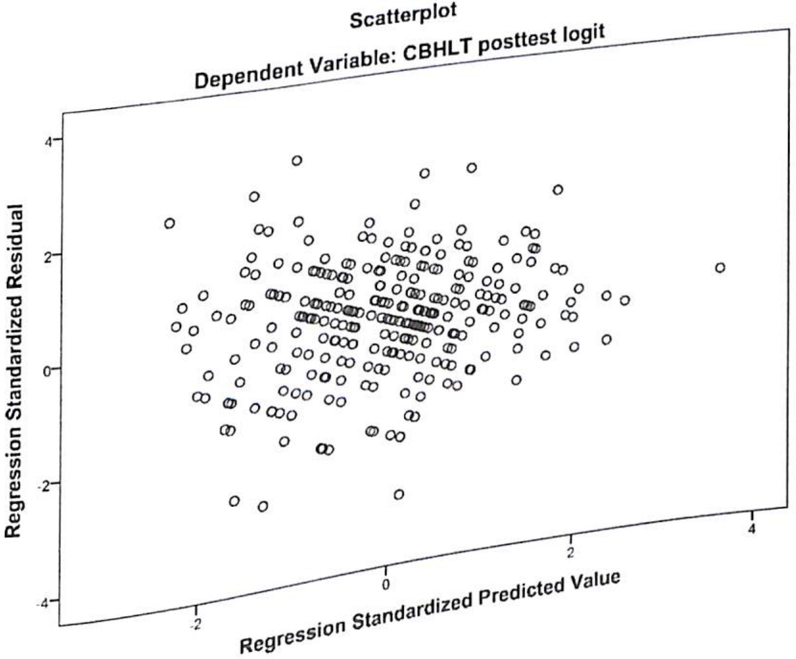
### Coefficients[a]

| Model | | 95.0% Confidence Interval for B | | Collinearity Statistics | |
|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Tolerance | VIF |
| 1 | (Constant) | -.371 | .099 | | |
| | PKCCT logit | .033 | .339 | .824 | 1.214 |
| | VRT logit | -.041 | .144 | .806 | 1.240 |
| | CBHLT pretest logit | .341 | .537 | .937 | 1.067 |
| | gender | -.095 | .162 | .953 | 1.049 |

a. Dependent Variable: CBHLT posttest logit


Histogram
Dependent Variable: CBHLT posttest logit
Mean = -5.00E-16
Std. Dev. = 0.991
N = 287
Frequency
50
40
30
20
10
0
-4
-2
0
2
4
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: CBHLT posttest logit
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob


Scatterplot
Dependent Variable: CBHLT posttest logit
Regression Standardized Residual
4
2
0
-2
-4
-2
0
2
4
Regression Standardized Predicted Value

# Appendix Y

## Sample Rubric Tools

### Rubric for the Evaluation of Laboratory Notebook and Laboratory Report

*Modified Hoyo Critical Thinking Evaluation Rubric for Written Reports.*

| Trait Evaluated | Cognitive Skill Applied | Level or Score | Criterion for obtaining levels (scores) of the rubric |
|---|---|---|---|
| Abstract | Synthesis | 3 | All main points of information are succinctly presented. The title/ purpose, hypothesis' research question is clearly stated. The purpose is written in a professional way in less than 100 words long and contains a clear articulation of thesis statement or argument. |
| | | 2 | Some points of information or keywords are missing, but all the criteria are addressed. |
| | | 1 | One or more criteria are absent |
| Sources of Information | Knowledge and Evaluation | 3 | Sources of information are appropriately cited in the document. A thorough research of the literature was conducted. The nature of the sources is judged to be appropriate. Citations are consistently formatted. |
| | | 2 | An effort on all criteria is shown. |
| | | 1 | One or more criteria are absent. |
| Organization | Analysis | 3 | Clear section headings are used in the document. Material is presented under the appropriate heading. Information is presented in reasonable amounts. There is a logical and coherent flow of information throughout the document. |
| | | 2 | Either one of the last two criteria not met. Contains clear section headings with relevant material in each section. |
| | | 1 | Requires major improvements on all criteria. |
| Relevance | Knowledge and Application | 3 | Appropriate scientific terminology is used. The writing in the report integrates information from class, lecture and activities into new material. The student can provide a link between theory and applications. |
| | | 2 | One criterion is lacking, but efforts on the other two are shown. |
| | | 1 | Scientific terminology is used, but none of the other criteria are met. |
| Content | Comprehension | 3 | The student's writing conveys new information in the students 'own words. Concepts are correctly understood. An appropriate depth of content is present. The writing in the report is simple and direct. The students write in the active voice rather than passive voice. |
| | | 2 | The material in the report is not well understood, but effort is shown towards comprehension. |
| | | 1 | The content is too broad. The focus is not on scientific aspect of the topic. |
| Presentation | Evaluation | 3 | The report is well written in English and has professional appearance: typewritten, neat and easy to read. All previous formative evaluations were addressed. The presentation conforms to the required format. |
| | | 2 | Efforts on all criteria were made, but not fully achieved. |
| | | 1 | One or more of the criteria are not met. |

*Note:* Rubric for evaluating written reports. Reprinted from "Designing a written assignment to promote the use of critical thinking skills in an introductory chemistry course," by M.T. Oliver-Hoyo, 2003, *Journal of Chemical Education 80(8)*, p. 900. Copyright 2003 by American Chemical Society. Reprinted with permission.

## Rubric for Arguments using Toulmin Argumentation Pattern

A. **Validity of Data in Argument**
Actual data is used; valid assumption- or inference-based, sophisticated – 2 points
Assumption- or inference-based, but simplistic – 1 point
Invalid/ Misinterpretation of data – No point

B. **Quality of Links in Argument**
Correct, chemistry-based or mechanistic reasoning – 2 points
Correct but non-mechanistic chemistry reasoning – 1 point
Incorrect reasoning/ simplistic or naïve reasoning – 1 point

C. **Validity of Data in Rebuttal**
Actual data is used; valid assumption- or inference-based, sophisticated – 2 points
Assumption- or inference-based, but simplistic – 1 point
Invalid/ Misinterpretation of data – No point

D. **Quality of Links in Rebuttal**
Correct, chemistry-based or mechanistic reasoning – 2 points
Correct but non-mechanistic chemistry reasoning – 1 point
Incorrect reasoning/ simplistic or naïve reasoning – 1 point