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Development and Rasch Analysis of the Prior Knowledge of Chemistry Concepts Test for Pre-medical Students in the Philippines

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ABSTRACT

Chemistry concepts are embedded in several contexts that are related to the future professional roles of pre-medical students. In the current academic landscape of pre-medical programs, an objective measurement of prior knowledge of chemistry concepts is necessary to promote students' academic success. To address this issue, this study aimed to develop and validate the *Prior Knowledge of Chemistry Concepts Test*. This multiple-choice research instrument is designed to measure pre-medical students' knowledge of essential chemistry concepts from pre-requisite chemistry courses in pre-medical programs in the Philippines. The final item pool, consisting of 26 general chemistry concepts and 21 general organic chemistry concepts was administered to 470 college students from four tertiary institutions in the Philippines. Item content validity indices (I-CVI) and *kappa* statistics guided initial revisions, while dichotomous Rasch analysis was utilized to determine the psychometric properties of the research instrument. The analysis provided evidence of adequate person and item reliability, item fit, local independence, and unidimensionality, although some items may be omitted in subsequent iterations. The application of the research instrument to assessment and evaluation was elaborated using the student ability and item difficulty logits along the person-item map. Suggestions for the improvement of the research instrument were also discussed.

Keywords: *pre-medical students, pre-requisite chemistry courses, prior knowledge, Rasch analysis*

INTRODUCTION

In pre-medical programs, students are desired to develop adequate conceptual knowledge and understanding of science concepts and apply them to clinical and community healthcare decision-making tasks. Science concepts accentuate logical connections and promote a critical evaluation of evidence to support decisions that require multidisciplinary perspectives (von Winterfeldt, 2013). Science courses aim to improve students' conceptual understanding by increasing their procedural knowledge (Krell et al., 2023), and refining their reasoning skills. Several decisions related to health contexts (i.e., nutrition, pharmacology, disease causation, and diagnostics) rely on an adequate conceptual understanding of related chemistry concepts (Armstrong and Pöe, 2020; Azzalis et al., 2012; Barcelo and Ferido, 2023; Brown et al., 2014; Harrison et al., 2012). Furthermore, knowledge of chemistry concepts also promotes adequate risk and hazard perception of chemicals in academic and hospital settings (Álvarez-Chávez et al., 2019; Al-Zyoud et al., 2019; Charlier et al., 2021), empowering pre-medical students to apply appropriate risk mitigation strategies. Reforms to improve the teaching strategy for chemistry courses in pre-medical programs are among the relevant thrusts in the current educational landscape (Shulman, 2013; Matlin et al., 2017). Caution, however, is reminded to highlight the notion that pre-requisite science courses such as chemistry are designed to develop pre-medical students' critical thinking skills and evaluate evidence conscientiously (Brown et al., 2014; Harrison, 2005) and not to achieve a high level of mastery that is expected from science experts.

Unfortunately, general chemistry courses are usually perceived by students to be irrelevant (Hofstein and Mamlok-Naaman, 2011) or difficult (Cardellini, 2012; Gillespie, 1991; O'Dwyer and Childs, 2017). Pre-medical students share this perception (Barr et al., 2010; Boddey and de Berg, 2018), and consider chemistry as a gatekeeper course. While biochemistry is regarded as the most relevant to health professions (Azzalis et al., 2012; Brown et al., 2014; Goeden et al., 2015; Harrison et al., 2012), there is recent evidence that other prerequisite chemistry courses (i.e., general chemistry, organic chemistry, analytical chemistry) improve critical thinking of students in medical education (Dixson et al., 2022; Hashemzadeh and Peyton, 2016). Previous studies reported that college students struggle with general chemistry topics such as stoichiometry and mole concepts (Ralph and Lewis, 2018). In addition, college students also find organic chemistry concepts difficult or unrelated to professional practice (Cooper et al., 2018; O'Dwyer & Childs, 2017). The difficulty of chemistry concepts was linked to a lack of familiarity or prior knowledge of the concepts (Broman et al., 2020; Cardellini, 2012), although poor academic performance in chemistry was also associated with students' demographic, affective, and cognitive traits (Ralph and Lewis, 2018).

Pre-medical Students' Prior Knowledge of Chemistry Concepts: Why Does it Matter? In the science courses of pre-medical programs, the measurement of students' prior knowledge is necessary for designing learning materials and implementing relevant educational interventions that achieve the desired program outcomes. Students' prior knowledge of concepts is a crucial factor to consider when designing a curriculum or using an advanced approach that requires the application of a multidisciplinary perspective in learning concepts (Hailikari et al., 2008). In addition, prior knowledge of concepts also influences learning engagement (Dong et al., 2020) and learning readiness (Puji et al., 2020). Prior knowledge, combined with curiosity, also boosts the actual learning trajectory of students (Wade and Kidd, 2019). In pre-medical programs, a high level of prior knowledge discourages surface learning and rote memorization (Hailikari et al., 2008), preparing students to learn professional courses requiring multidisciplinary perspectives. Prior knowledge is also cited as a predictor of academic achievement (Binder et al., 2019), allowing an early design of learning activities that promote effective learning of new concepts. These findings support the need to measure the prior knowledge of pre-medical students, as chemistry courses are offered as prerequisites before enrolling in professional courses. But why does it matter? The array of knowledge that is required in pre-medical programs is not the same as that required in science majors. Hence, the depth of knowledge should be contextualized to what is required in professional practice because expert levels of scientific knowledge are seldom required in actual clinical decisions.

Since chemistry courses are prerequisites of professional courses in pre-medical programs, it is necessary to objectively measure the pre-medical students' knowledge of prerequisite chemistry concepts that are related to professional practice since these concepts are embedded in health contexts (Shulman, 2013). Furthermore, it has been acknowledged that prior knowledge of chemistry concepts promotes the development of critical thinking among pre-medical students (Dixson et al., 2022). However, there is a need to reevaluate the concepts to be taught in prerequisite chemistry courses for pre-medical programs. This is in response to the observation that chemistry courses discourage pre-medical students from continuing their programs (Barr et al., 2010). While several studies have highlighted the chemical basis of health concepts (Armstrong and Pöe, 2020; Matlin et al., 2017; Shulman, 2013), curriculum revisions are necessary to promote the successful integration of relevant chemistry concepts into the future professional practice of pre-medical students while encouraging them to continue pursuing their programs and enrol in medical courses. It is also clear that different pre-medical programs (e.g., BS Nursing, BS Pharmacy, or BS Medical Technology) have varied types of chemistry prerequisites, and each chemistry course may differ depending on the emphasis on each program.

Application of Rasch Analysis in Chemistry Research Instrument Development and Validation. The objective measurement of knowledge of chemistry concepts has been addressed in literature by applying Rasch analysis in developing and validating research instruments in chemistry education**.** An early effort to develop a research instrument that measures students' understanding of chemistry concepts was described by Potgieter et al. (2005). In their study, Rasch analysis was utilized to determine the properties of a concept inventory in chemistry that is designed for Grade 12 learners. The concept inventory included topics in general chemistry, organic chemistry, mathematical skills, language skills, and process skills. Yamtinah et al. (2022) also applied Rasch analysis to evaluate the validity and reliability of a chemistry test that measures conceptual understanding of stoichiometry. Furthermore, the authors conducted a distractor analysis to determine the quality of the items. In the study of Nedungadi et al. (2019), a concept inventory that develops proficiency in organic reaction mechanisms was developed and analyzed using the dichotomous Rasch model and established the hierarchy of concepts related to the underlying construct. Rasch analysis was also used to improve a multiple-choice chemistry exam for university students on a semester-to-semester basis (Sorenson and Hanson, 2021). The Rasch model was also used to evaluate the Chemical Concept Inventory and determine the learning gains of first-year university students (Pentecost and Barbera, 2013). Rasch analysis was also applied to evaluate the psychometric properties of multiple-choice research instruments in chemistry (Nedungadi et al., 2019; Pentecost and Barbera, 2013). Lastly, Jin et al. (2020) also applied the Rasch model and performed distractor analysis for the 18-item Redox Concept Inventory. In these studies, the item and person reliability and separation, item difficulty, item fit, and unidimensionality, were evaluated to guide the revision of the tests.

In the Philippine setting, there is a dearth of literature about the development of research instruments that objectively measure pre-medical students' knowledge of chemistry concepts. Measuring students' prior knowledge of chemistry concepts using Rasch analysis can potentially promote educational reforms that encourage academic success in prerequisite chemistry courses in pre-medical programs. Objective measurement of previous understanding of chemistry concepts allows identifying students who may change career plans because of their low performance in chemistry courses, such as organic chemistry (Lovecchio and Dundes, 2002). Negative experiences with chemistry cause poor academic performance, and poor performance can cause anxiety (Boddey and de Berg, 2018) and prods students to leave pre-medical programs (Lin et al., 2013). Addressing these issues early in the academic experience of pre-medical students allows the design of learning materials and educational interventions that can improve conceptual knowledge in pre-requisite chemistry courses. Equitable pre-medical education provides equal opportunities for all students, and preventing attrition is one of the strategies to ensure the successful completion of pre-medical programs (Ralph and Lewis, 2018).

While advanced chemistry knowledge is seldom required in pre-medical programs, some chemistry topics guide students in making logical connections during important decision-making tasks. In addition, prior knowledge of chemistry concepts promotes meaningful connections with more advanced chemistry concepts (Cooper & Stowe, 2018). Furthermore, basic chemistry concepts are interwoven with physiologic processes, suggesting the need to use students' prior knowledge of chemistry concepts as a conceptual scaffold in chemical and biochemical systems. Cooper et al. (2018) emphasized the need to connect topics to core ideas and not merely add relevant examples to the conventional practice of teaching chemistry concepts. In the same argument, core concepts in pre-medical programs need to be linked to health contexts by promoting the progression of the prior knowledge of chemistry concepts and explicitly linking them to *in vivo* chemical systems, emphasizing their difference from typical *in vitro* chemical environments that are studied in chemistry laboratory courses. At present, the measurement of the prior knowledge of pre-medical students on chemistry concepts is undocumented, and a call for developing a research instrument with adequate psychometric properties is warranted to serve as a basis for measuring and comparing students' knowledge of pre-requisite chemistry concepts that are relevant to health professional practice.

Developing a research instrument requires a conceptualization of the construct to be measured by the instrument. In this study, "*prior knowledge of chemistry concepts*" is contextualized to the educational landscape of pre-medical programs in the Philippines. Chemistry courses (e.g., general chemistry, general organic chemistry, analytical chemistry, and biochemistry) are pre-requisite courses to professional courses, and only essential chemistry topics that are required in professional practice are included in the syllabi. Compared to students in the BS Chemistry programs, pre-medical students are required to learn chemistry concepts in health contexts. Hence, chemistry courses offered in science programs are not equivalent to their counterparts in pre-medical programs. It is also recognized that different pre-medical programs require different chemistry concepts to be learned. Certain chemistry topics are essential to understanding the pathology of diseases, elucidating the mechanism of action of pharmacological agents, and interpreting chemical tests that are involved in the diagnosis of diseases. Seemingly, each pre-medical program requires varying levels of conceptual knowledge in chemistry.

Currently, the curriculum of pre-medical programs includes one semester of general chemistry or general inorganic chemistry, followed by one semester of organic chemistry and one semester of biochemistry (Shulman, 2013). In the Philippine curriculum, one semester is equivalent to five months. In some cases, general chemistry, organic chemistry, and biochemistry are integrated into a single chemistry course (Brown et al., 2014; Frost et al., 2006). Commonly discussed topics in general chemistry and organic chemistry courses include atomic structure, bonding, equilibrium, acids and bases, intermolecular forces, functional groups, and solution chemistry (Brown et al., 2012; Frost et al., 2006; Mahaffey, 2019). It was also suggested that topics such as thermodynamics, dosage, and toxicity should also be included among the chemistry topics to be discussed in health contexts (Armstrong and Pöe, 2020). In the BS Pharmacy program, structure-property relationships and medicinal chemistry were also necessary to understand therapeutic decisions related to pharmacology (Harrold and McFalls, 2010; Fernandes, 2018). Hence, prior knowledge of chemistry concepts is defined in this study as the "*conceptual knowledge of essential and relevant general chemistry and general organic chemistry in pre-medical programs in the Philippines*."

This study focused on the development and validation of a research instrument that is designed to measure pre-medical students' prior knowledge of general chemistry and general organic chemistry concepts using the Rasch model. The research instrument was developed using a multiple-choice format based on the recommendations provided by Towns (2014). Rasch analysis helps determine the psychometric properties of multiple-choice tests, thereby allowing an objective measurement of student abilities on an invariant linear scale (Boone and Scantlebury, 2006). Rasch analysis allows comparison of student performance and provides robust evidence that informs curriculum revisions and reforms in chemistry education. Item content validity indices were also determined before applying Rasch measurement theory. This study was guided by the following research questions: (1) What are the item content validity indices of the *Prior Knowledge of Chemistry Concepts Test*? And (2) Is there evidence of validity and reliability of the *Prior Knowledge of Chemistry Concepts Test*?

METHODS

Design and development of the research instrument. The first version of the *Prior Knowledge of Chemistry Concepts Test* (PKCCT) was originally composed of 54 multiple-choice items that included topics from the general chemistry and general organic chemistry courses in pre-medical programs in the Philippines. The course syllabi for general chemistry and general organic chemistry from five tertiary-level institutions offering pre-medical programs such as BS Medical Technology and BS Pharmacy were compared to select the topics to be included in the initial draft of the instrument. Furthermore, previous studies that reported relevant topics to be discussed in pre-medical programs (Brown et al., 2012; Brown et al., 2014) were reviewed. The items were drafted by focusing on essential chemistry topics that are commonly applied in health professions. The hypothesized difficulty of each item in the initial draft of the research instrument was evaluated by five college teachers with a minimum of five years of experience teaching general inorganic chemistry, organic chemistry, and biochemistry to pre-medical students.

The final version of the test comprised 47 multiple-choice items, 26 items related to general chemistry concepts, and 21 items related to general organic chemistry concepts. A multiple-choice format was used in developing the test. To address the limitations of the multiple-choice format, the recommendations suggested by Towns (2014) were followed, such as including distractors, and randomizing the placement of correct responses on conceptual items. Table 1 summarizes the details of items in the *Prior Knowledge of Chemistry Concepts Test*. The percentage distribution of general chemistry (GC) and general organic chemistry (GOC) was based on the list of topics in the course syllabi from five tertiary institutions in the Philippines. The distribution of items classified as recall or comprehension (RC) and application or analysis (AA) was based on the course learning outcomes stipulated in the general chemistry and general organic chemistry courses in the syllabi for pre-medical programs. The items in the research instrument represented the essential and relevant pre-requisite concepts that pre-medical students commonly encounter in biochemistry and professional courses such as clinical chemistry, community and public health, or pharmacology.

Item Content Validity of the Prior Knowledge of Chemistry Concepts Test. Item content validity index (I-CVI) was determined to ensure that the items were relevant to the measurement of prior knowledge of chemistry concepts. The test was validated by three Ph.D. Chemistry professors from Manila, one Ph.D. Biochemistry professor from Laguna, and one Ph.D. Chemistry Education professor from Benguet. I-CVI and *kappa* statistics were obtained based on the procedure described in previous studies (Polit et al., 2007; Shrotryia and Dhanda, 2019). The I-CVI and *kappa* statistics were used as references for further deletion or revision of the items. The comments of the validators were incorporated into the revised item. The decision to delete the items was based on reviewers' comments and obtained an I-CVI that is less than 0.79, which is interpreted to be "*not relevant*." However, some items were revised if the concepts are essential concepts that are required in professional courses. Based on the initial results of the evaluation, seven items were deleted. An example of an item with I-CVI < 0.79 is shown below.

Table 1. Details of items in the *Prior Knowledge of Chemistry Concepts Test.*

Item	Item description	Type[a]	Concept[b]
Item 01	Conceptual understanding of accuracy and precision	RC	GC
Item 02	Analysis of the mole concept	AA	GC
Item 03	Conceptual understanding of ionization	RC	GC
Item 04	Conceptual understanding of quantum number	RC	GC
Item 05	Conceptual understanding of periodic properties	RC	GC
Item 06	Conceptual understanding of malleability	RC	GC
Item 07	Identification of intermolecular force of attraction*	RC	GC
Item 08	Analysis of the relationship of vapor pressure with solute*	AA	GC
Item 09	Conceptual understanding of dialysis*	RC	GC
Item 10	Conceptual understanding of boiling point	RC	GC
Item 11	Determination of the empirical formula	RC	GC
Item 12	Analysis of molecular polarity	AA	GC
Item 13	Conceptual understanding of meniscus formation	RC	GC
Item 14	Conceptual understanding of osmotic pressure	AA	GC
Item 15	Analysis of a chromatography problem	AA	GC
Item 16	Analysis of solubility based on molecular polarity	AA	GC
Item 17	Analysis of density	AA	GC
Item 18	Conceptual understanding of acid-base pair	RC	GC
Item 19	Analysis of a buffer system*	AA	GC
Item 20	Conceptual understanding of oxidation number	RC	GC
Item 21	Conceptual understanding of redox reaction	RC	GC
Item 22	Conceptual understanding of molar mass	RC	GC
Item 23	Conceptual understanding of chemical equilibrium*	RC	GC
Item 24	Conceptual understanding of enthalpy of reaction	RC	GC
Item 25	Application of Hess Law*	AA	GC
Item 26	Analysis of coordinate diagram (exothermic reaction) *	AA	GC
Item 27	Conceptual understanding of pi orbitals	RC	GOC
Item 28	Analysis of molecular formula of alkanes	AA	GOC
Item 29	Application of IUPAC nomenclature of alkenes*	AA	GOC
Item 30	Determination of the hybridization of carbon atoms*	RC	GOC
Item 31	Conceptual understanding of bond strength	RC	GOC
Item 32	Analysis of chiral carbons in a structure*	AA	GOC
Item 33	Conceptual understanding of isomerism	RC	GOC
Item 34	Conceptual understanding of the boiling point of alkanes	RC	GOC
Item 35	Analysis of oxidation for $KMnO_4$ test of unsaturation	AA	GOC
Item 36	Conceptual understanding of resonance	RC	GOC
Item 37	Analysis of stereochemistry*	AA	GOC
Item 38	Analysis of aromatic structures*	AA	GOC
Item 39	Analysis of electrophilic aromatic substitution	AA	GOC
Item 40	Analysis of the molecular structure of aldehyde*	AA	GOC
Item 41	Analysis of the reduction of primary alcohol	AA	GOC
Item 42	Analysis of oxidation of 1^o, 2^o and 3^o alcohol*	AA	GOC
Item 43	Analysis of the reduction of a ketone	AA	GOC
Item 44	Application of IUPAC nomenclature of aromatic structure*	AA	GOC
Item 45	Analysis of boiling point of carboxylic acids	AA	GOC
Item 46	Analysis of acidity of benzoic acid	AA	GOC
Item 47	Conceptual understanding of nucleophilic acyl substitution	RC	GOC

Note: [a]RC = recall or comprehension, AA = application or analysis; [b]GC **=** general chemistry, GOC = general organic chemistry; items with * were presented with visual representations

Item 16 (deleted item, I-CVI = 0.60)

When water is boiling, several bubbles rise to the surface. What do these bubbles contain?

A. Oxygen gas
B. Water vapor
C. Hydrogen gas
D. Atmospheric air

Comments:
Multiple answers are possible since dissolved gases can also escape in the form of bubbles. (Reviewer 1)

You need to qualify that the bubbles you are referring to are those that form when the water has been boiling continuously for some time. At the start of boiling, some of the bubbles may contain dissolved air. (Reviewer 4)

Ethics Approval. The protocol for conducting the pilot test was submitted for ethics review to the Saint Louis University-Research Ethics Committee on March 6, 2019. The protocol was approved on March 21, 2019, and assigned with the ethics approval certificate SLU-REC 2019-045.

Pilot Testing. After securing ethics approval, a total of 472 students, composed of 46 second-year BS Chemistry students from one institution in Los Baños, Laguna (completed inorganic chemistry and general organic chemistry), 112 first-year medical technology students from one institution in Manila (completed general chemistry and organic chemistry), 214 first-year pharmacy students from a tertiary institution in Baguio City (completed general chemistry only) and 100 second-year medical technology students in a tertiary institution in Baguio City (completed general chemistry and general organic chemistry) were recruited to answer the final version of the *Prior Knowledge of Chemistry Concepts Test*. Theoretically, the 2nd year BS chemistry students should exhibit a higher prior knowledge of chemistry concepts and be expected to score higher on the test. On the other hand, students who have not yet completed general organic chemistry courses were expected to score lower on the test. Before answering the research instrument, the respondents were requested to read the informed consent form according to ethical guidelines. Only respondents who signed the informed consent form answered the test. Two students who did not sign the informed consent form were excluded from the analysis of data.

Rasch Analysis. The results were evaluated using the dichotomous Rasch model using WINSTEPS version 4.4.5. Dichotomous Rasch analysis is commonly used in multiple-choice tests (Boone, 2016) and is based on the mathematical model:

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

where $\boldsymbol{B_n}$ is the ability of the person $\boldsymbol{n}$, $\boldsymbol{D_i}$ is the difficulty of item $\boldsymbol{i}$, and the probability ($\boldsymbol{P}$) 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 (log odd units), and may be presented in the same linear scale using what is called a person-item map or Wright Map.

Rasch parameters, such as the person and item reliability index and the person and item separation index, were evaluated initially to determine the quality of the research instrument. A person separation index of 1.50 is considered acceptable while a person separation index of 2.00 represents a good level of separation (Linacre, 2012). On the other hand, misfitting items are identified by using rule-of-thumb critical values of item fit parameters, such as the infit and outfit mean squares (MNSQ) and outfit and infit normalized Z-score of the residual (ZSTD) (Planinic et al., 2019). The MNSQ values between 0.70 to 1.30 and ZSTD values between -2 to +2 were used based on recommendations (Bond and Fox, 2013; Boone et al., 2013). The outfit MNSQ values were considered more sensitive to outliers, so the infit MNSQ was prioritized when evaluating misfitting items (Neumann et al., 2013). Furthermore, MNSQ values should be prioritized over ZSTD values if the sample size is greater than 250 (Aryadoust et al., 2020). If an item exhibits a misfit, there is a need to examine the wording, scoring, or content (Planinic et al., 2019) to guide further iterations in finalizing the research instrument. To determine whether items are contributing to the measurement of the construct, the point-measure correlation should be greater than an absolute value of 0.30 (Li et al., 2016). Lastly, the principal component analysis (PCA) on standardized residuals was evaluated to evaluate local independence. To support unidimensionality, an eigenvalue of the first contrast less than 2.0 is considered acceptable (Linacre, 2012).

RESULTS AND DISCUSSION

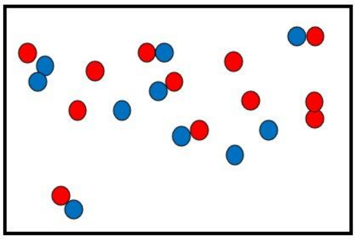
Item Content Validity Indices. Table 2 shows that the item content validity indices (I-CVI) of the *Prior Knowledge of Chemistry Concepts Test* were fair to excellent. Items that were rated as "fair" were reviewed and revised based on the reviewers' comments. Item 16 (analysis of solubility based on molecular polarity) was shortened to improve its clarity. Item 23 (analysis of chemical equilibrium) was revised by replacing the image. Lastly, Item 24 (analysis of enthalpy of reaction) was revised by providing a balanced chemical equation. The revisions done on Item 23 are presented below.

Original Item 23 (I-CVI = 0.80)

From the chemical reaction:

$$A_{(g)} + B_{2(g)} \rightleftharpoons AB_{(g)} + B_{(g)}$$

The resulting mixture is illustrated below. (red circle = A, blue circle = B)



If the K at equilibrium is 1.5, what does this mixture imply?

A. The system will proceed towards production of $AB_{(g)}$ and $B_{(g)}$.
B. The system will be proceeding towards the production $AB_{(g)}$ only.
C. The system will proceed towards the production of A and $B_{2(g)}$.
D. The system will proceed towards the production of $B_{2(g)}$ only.

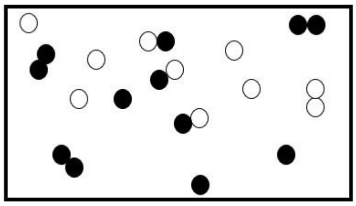
Comments:
Reviewer 1: *The diagram is useful.*
Reviewer 2: *Mention Le Chatelier's principle.*
Reviewer 3: *You may add more of $B_{2(g)}$ in the diagram.*

Revised Item 23

From the chemical reaction:

$$A_{(g)} + B_{2(g)} \rightleftharpoons AB_{(g)} + B_{(g)}$$

The resulting mixture is illustrated below (white circle = A, black circle = B).



If the K at equilibrium is 1.5, what does this mixture imply based on Le Chatelier's principle?

A. The system will proceed toward the production of $AB_{(g)}$ and $B_{(g)}$.
B. The system will proceed towards the production $AB_{(g)}$ only.
C. The system will proceed towards the production of A and $B_{2(g)}$.
D. The system will proceed toward the production of $B_{2(g)}$ only.

Item and Person Separation and Reliability and Fit Statistics. Table 3 summarizes the Rasch analysis results of the *Prior Knowledge of Chemistry Concepts Test*. The 47 items of the research instrument exhibited adequate reliability (item reliability = 0.97, person reliability = 0.86) and separation (item separation = 5.84, person separation = 2.51). All infit and outfit MNSQ values were between 0.70 to 1.30, indicating that the items fit the Rasch model. However, nine items (Item 07, Item 08, Item 23, Item 24, Item 27, Item 28, Item 31, Item 44, and Item 46) had ZSTD values that are not within -2 to +2. Since the sample size was greater than 250, the MNSQ values were prioritized as a basis for item fit based on the recommendations of Aryadoust et al. (2020). However, items that exhibited ZSTD values lower than -2 or greater than +2 need to be investigated further as they indicate potential item misfit. An item exhibits a misfit if low-performing students unexpectedly answer a difficult item, or high-performing students unexpectedly answer easy items incorrectly (Boone, 2016). To ensure that the research instrument is in good agreement with objective measurement (Planinic et al., 2019), misfitting items need to be dropped from the final list of items (Boone, 2016). Since these items still exhibited adequate infit and outfit MNSQ, the items need to be reviewed in future iterations.

Local Independence and Unidimensionality. The first eigenvalue for PCA on Rasch residuals was 2.28. This value is slightly higher than the recommended value of less than 2 eigenvalues (Linacre and Tennant, 2009). However, the largest standardized residual correlations were measured at 0.15 (Item 36 and Item 37), and 0.14 (Item 12 and Item 34). The residual correlations imply that the variance between Item 36 and Item 37 (variance = 2.25%) and Item 12 and Item 34 (variance = 1.96%) are too low to distort the functioning of the research instrument. The results suggest that the *Prior Knowledge of Chemistry Concepts Test* satisfied the requirement for local independence unidimensionality.

Table 2. Item content validity indices (I-CVI) and *kappa* statistics of the final items of the *Prior Knowledge of Chemistry Concepts Test*.

Item	I-CVI	I-CVI Interpretation	*pc*	*k*	*k* interpretation
Item 01	1.000	Appropriate	0.031	1.000	Excellent
Item 02	1.000	Appropriate	0.006	1.000	Excellent
Item 03	1.000	Appropriate	0.006	1.000	Excellent
Item 04	0.800	Appropriate	0.031	0.794	Excellent
Item 05	1.000	Appropriate	0.006	1.000	Excellent
Item 06	0.800	Appropriate	0.031	0.794	Excellent
Item 07	0.800	Appropriate	0.031	0.794	Excellent
Item 08	0.800	Appropriate	0.031	0.794	Excellent
Item 09	0.800	Appropriate	0.031	0.794	Excellent
Item 10	0.800	Appropriate	0.031	0.794	Excellent
Item 11	0.800	Appropriate	0.031	0.794	Excellent
Item 12	1.000	Appropriate	0.006	1.000	Excellent
Item 13	1.000	Appropriate	0.006	1.000	Excellent
Item 14	0.800	Appropriate	0.031	0.794	Excellent
Item 15	0.800	Appropriate	0.031	0.794	Excellent
Item 16	0.600	Revise	0.063	0.573	Fair
Item 17	0.800	Appropriate	0.031	0.794	Excellent
Item 18	0.800	Appropriate	0.031	0.794	Excellent
Item 19	0.800	Appropriate	0.031	0.794	Excellent
Item 20	0.800	Appropriate	0.031	0.794	Excellent
Item 21	0.800	Appropriate	0.031	0.794	Excellent
Item 22	0.800	Appropriate	0.031	0.794	Excellent
Item 23	0.600	Revise	0.063	0.573	Fair
Item 24	0.600	Revise	0.063	0.573	Fair
Item 25	0.800	Appropriate	0.031	0.794	Excellent
Item 26	1.000	Appropriate	0.006	1.000	Excellent
Item 27	0.800	Appropriate	0.031	0.794	Excellent
Item 28	0.800	Appropriate	0.031	0.794	Excellent
Item 29	0.800	Appropriate	0.031	0.794	Excellent
Item 30	1.000	Appropriate	0.006	1.000	Excellent
Item 31	0.800	Appropriate	0.031	0.794	Excellent
Item 32	1.000	Appropriate	0.006	1.000	Excellent
Item 33	0.800	Appropriate	0.031	0.794	Excellent
Item 34	0.800	Appropriate	0.031	0.794	Excellent
Item 35	1.000	Appropriate	0.006	1.000	Excellent
Item 36	1.000	Appropriate	0.006	1.000	Excellent
Item 37	1.000	Appropriate	0.006	1.000	Excellent
Item 38	0.800	Appropriate	0.031	0.794	Excellent
Item 39	0.800	Appropriate	0.031	0.794	Excellent
Item 40	1.000	Appropriate	0.006	1.000	Excellent
Item 41	0.800	Appropriate	0.031	0.794	Excellent
Item 42	0.800	Appropriate	0.031	0.794	Excellent
Item 43	1.000	Appropriate	0.006	1.000	Excellent
Item 44	1.000	Appropriate	0.006	1.000	Excellent
Item 45	1.000	Appropriate	0.006	1.000	Excellent
Item 46	1.000	Appropriate	0.006	1.000	Excellent
Item 47	1.000	Appropriate	0.006	1.000	Excellent

Note: I-CVI = item content validity index; *pc* = chance agreement; *k* = *kappa* statistics

Table 3. Summary of reliability, separation, and fit statistics of the *PKCCT* items.

Rasch parameters	Min	Max	Median
Item Measures	-1.33	1.52	0.54
Standard Error	0.10	0.12	0.10
Infit MNSQ	0.90	1.11	0.99
Outfit MNSQ	0.86	1.19	0.98
Infit ZSTD	-2.83	2.76	-0.13
Outfit ZSTD	-2.88	3.13	-0.30
Point Measure Correlation	0.26	0.49	0.39
Item Separation Index (Reliability)	5.84 (0.97)		
Person Separation Index (Reliability)	2.51 (0.86)		

Person-item Map. Figure 1 shows the item-person map or Wright map of the data set for the *Prior Knowledge of Chemistry Concepts Test*. The Wright map (person-item map) allows the examination of the spacing and order of items (Davis and Boone, 2021) and informs researchers on future revisions of the research instrument. The range of person ability is -2.49 t0 3.22 logits, while the range of item difficulty is -1.33 to 1.52 logits. This means that the range of item difficulties is within the ability of the target respondents in the study. The result indicates adequate targeting of the test to the sample (Planinic et al., 2019), and the difficulty of the test is appropriate for pre-medical students who have yet to take up pre-requisite chemistry courses, and those who have completed all pre-requisite chemistry courses. Based on the item hierarchy, it can be observed that items that involved application and analysis were more difficult compared to items that required recall and understanding, thereby validating the hypothesized difficulty during instrument design. However, it can be noted that Item 27 (conceptual understanding of pi orbitals) and Item 36 (conceptual understanding of resonance) were considered difficult by the students, despite being classified as items that require recall and understanding. In addition, several items related to application or analysis exhibited similar difficulty levels, while gaps can be observed among items requiring recall and understanding. Items that are proximal to each other in the Wright map may suggest redundancy from a measurement perspective, while the difficulty gaps indicate the need to add items (Davis and Boone, 2021).

The application of Rasch analysis in developing research instruments that are used for the assessment and evaluation of student performance is relevant in chemistry education. In designing learning materials and educational interventions, it is important to use research instruments with adequate psychometric properties to allow an accurate interpretation of results and correctly guide curricular revisions. In this study, Rasch analysis was applied to determine the psychometric properties of the *Prior Knowledge of Chemistry Concepts Test*. This research instrument was designed to measure pre-medical students' conceptual knowledge of general chemistry and general organic chemistry concepts. The results indicate that the psychometric properties of the research instrument were adequate and may be used for potential diagnostic assessment of students in pre-medical programs. Furthermore, the item hierarchy indicates that students who have completed general chemistry courses (are more capable of answering items that require application and analysis than students who have not yet completed organic chemistry.

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                .### |  It19   It27   It36   It46   It47
              .##### |  It05   It15   It17   It18   It25   It26   It29
               .#### |M It20   It21   It24   It33   It34
             .###### |  It04   It45
           .######## |  It09   It44
   0           ##### M+ It22
               .#### |  It31
              ###### |S It03   It07   It13
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Figure 1. Person-item map of the data set in PKCCT

Rasch analysis has been utilized to develop and determine the construct validity of research instruments in chemistry. In the context of chemistry courses in pre-medical programs, Brown et al. (2014) also developed a chemistry test involving general, organic, and biochemistry (GOB), although the validity and reliability of the instrument were evaluated using the Classical Test Theory. In this study, only the concepts related to general inorganic chemistry and organic chemistry were included. Furthermore, Rasch analysis was applied to determine the instrument's psychometric properties. In the Philippines, Rasch analysis was applied to develop and analyze research instruments in chemistry that are contextualized to health science programs, such as the Chemistry-based Health Literacy Test (Barcelo and Ferido, 2023), and Chemical Identity Thinking

Instrument (Barcelo, 2023). The Chemistry-based Health Literacy Test was guided with a rubric that explicitly links chemistry concepts to relevant health contexts, such as nutrition, diagnostics, and pharmacology, thereby promoting the application of chemistry concepts to future health professional practice (Barcelo and Ferido, 2023). On the other hand, the Chemical Identity Thinking Instrument aimed to measure the progression of chemical identity thinking based on the reasoning patterns described by Ngai and Sevian (2016): *objectivization*, *principlism*, *compositionism*, and *interactionism*.

Rasch modelling has several advantages over the Classical Test Theory approach, as it provides evidence on construct validity and item difficulty and promotes the measurement of a trait along a linear scale (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. Factor analysis is commonly applied to determine instrument functioning and then used as evidence for the psychometric properties of the instrument. However, raw scores are not linear measures (Planinic et al., 2019), and item difficulties must be determined to accurately interpret results (Boone, 2016). Lastly, analyzing raw scores with statistics may produce distorted results (Planinic et al., 2019). Rasch theory guides in formulating an instrument that represents a range of "test-item difficulty" to its respondents (Boone, 2016). Using Rasch analysis, validated instruments can be developed to evaluate a curriculum's effectiveness and students' learning progress (Gotwals and Songer, 2013; Jin et al., 2019; Morell et al., 2017; Yao and Guo, 2017). Furthermore, Rasch analysis methods can also be used for multiple-choice tests. With these advantages, it is not surprising that several chemistry education studies have applied Rasch analysis.

Applications of Prior Knowledge of Chemistry Concepts Test in Assessment and Evaluation. Since Rasch analysis converts raw scores to linear measures (Boone and Scantlebury, 2006; Planinic et al., 2019), it is possible to objectively measure pre-medical students' prior knowledge of chemistry concepts along a scale using the *Prior Knowledge of Chemistry Concepts Test*. Furthermore, using the instrument allows the comparison of the ability of the sub-population of students in pre-medical programs. Table 4 shows the table that can be used to convert the students' raw scores to Rasch measures (logits). For instance, if the mean raw score of first-year students is 27, the mean student ability estimate is 0.73 logit. Chemistry educators in pre-medical programs can compare the mean student abilities and use the Wright map (Figure 2) to interpret the ability of the students in each item. The Wright map shows the hierarchy of items based on difficulty. Items that are located at the bottom of the variable map were easier for the students while items at the top were more difficult. Based on this premise, Item 16 (analysis of solubility based on molecular polarity) is the most difficult item, while Item 06 (conceptual understanding of malleability) is the easiest item. A mean student ability of 0.73 logits indicates that the first-year student can correctly answer 32 items with greater than 50% probability.

Table 4. Conversion table from raw scores to student ability estimates.

Score	Measure	SE	Score	Measure	SE	Score	Measure	SE
0	-4.90	1.84	16	-0.32	0.32	32	1.22	0.32
1	-3.66	1.02	17	-0.22	0.32	33	1.32	0.33
2	-2.93	0.73	18	-0.12	0.31	34	1.43	0.34
3	-2.49	0.61	19	-0.02	0.31	35	1.55	0.34
4	-2.17	0.54	20	0.07	0.31	36	1.67	0.35
5	-1.91	0.49	21	0.17	0.31	37	1.80	0.36
6	-1.69	0.45	22	0.26	0.31	38	1.94	0.38
7	-1.50	0.42	23	0.35	0.30	39	2.09	0.40
8	-1.33	0.40	24	0.45	0.30	40	2.25	0.42
9	-1.17	0.39	25	0.54	0.30	41	2.44	0.44
10	-1.03	0.37	26	0.63	0.31	42	2.65	0.48
11	-0.89	0.36	27	0.73	0.31	43	2.90	0.53
12	-0.77	0.35	28	0.82	0.31	44	3.22	0.60
13	-0.65	0.34	29	0.92	0.31	45	3.65	0.73
14	-0.54	0.33	30	1.01	0.31	46	4.37	1.01
15	-0.43	0.33	31	1.11	0.32	47	5.59	1.83

Note: Measures are expressed in logits; SE = standard error

In addition, the mean ability of first-year students can be compared to a different sub-population (e.g., second-year students). If the person ability is the same as the item difficulty (e.g., item on the person-item map is on the same level of a person), it indicates that the item can be answered correctly with a 50% chance by the person (Boone, 2016). If item ability is higher than the item difficulty, then the student can answer the item with greater than 50% probability. This interpretation can also be applied to the comparison of groups based on mean student abilities (Pentecost and Barbera, 2013). Based on table 4, if the mean raw score of second-year students is 31, the estimated mean student ability is 1.11 logits. If the mean student ability of second-year students is 1.11, and the mean student ability of first-year students is 0.73 (logit equivalent of a raw score of 27), both mean ability logits can be in the person-item map. When the mean ability logits are plotted in the person-item map (Figure 2), one can see that there are 11 items in between the two measures. Based on the interpretation presented by Boone (2016), second-year students are more likely to answer Item 02, Item 35, Item 43, Item 08, Item 12, Item 28, Item 37, Item 40, Item 42, and Item 14 with greater than 50% chance compared to first-year students. This indicates that second-year students are more likely to correctly answer items related to application and analysis compared to first-year students. By using the results, a chemistry educator can design learning materials that could enhance students' application and analysis of chemistry concepts during the first year. The results can also guide curriculum developers in promoting the progression of conceptual understanding and cognitive skills of pre-medical students in their chemistry courses. This approach can also be used to analyze pretest-posttest comparisons after introducing instructional materials or teaching interventions in chemistry courses for pre-medical students.

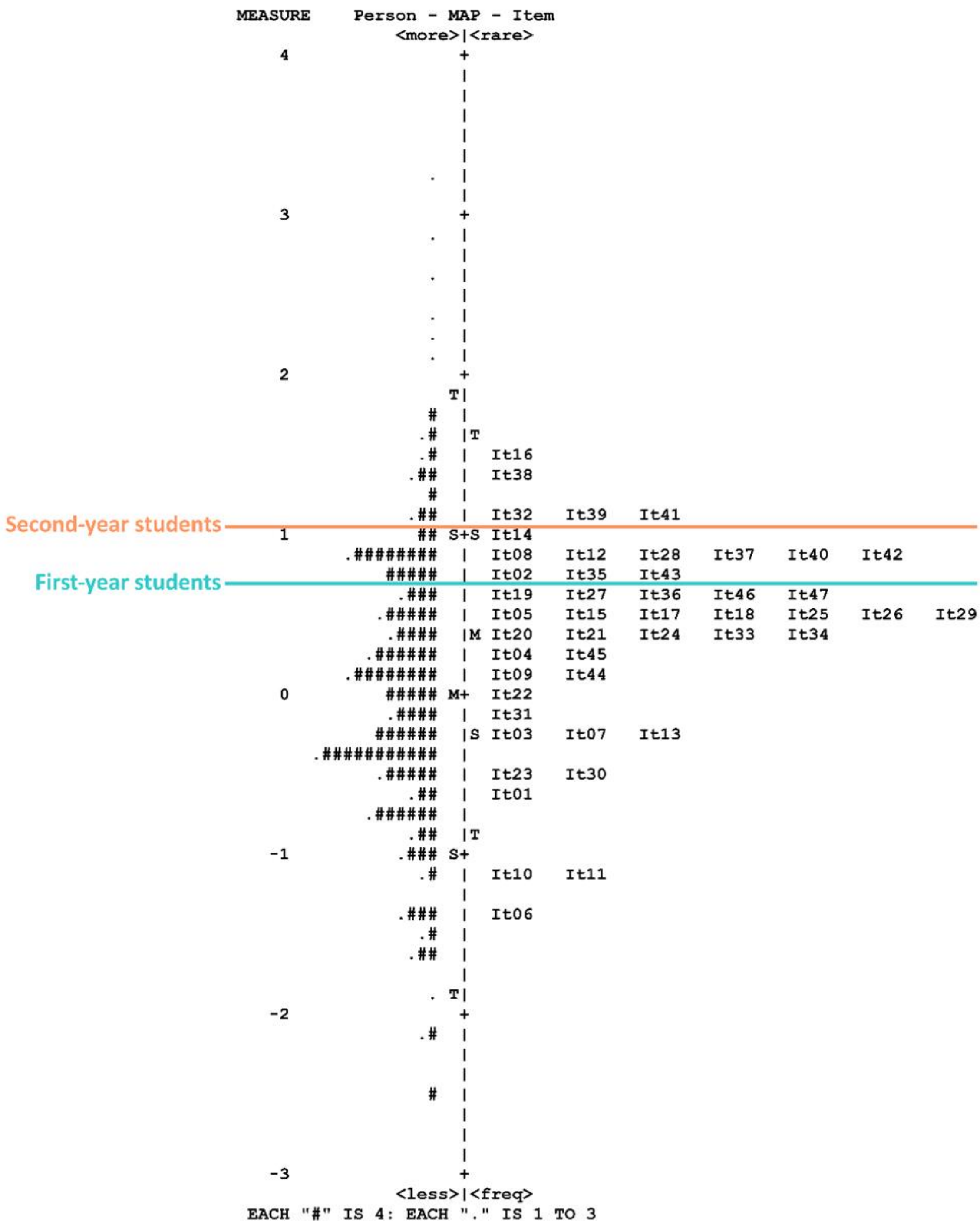

Figure 2. Person item map of PKCCT showing the mean ability measures of first-year and second-year students

There are several limitations of this study. While the results of the psychometric analysis of the *Prior Knowledge of Chemistry Concepts Test* are adequate, the application of this research instrument is only limited to determining the prior knowledge of selected chemistry concepts that are essential for pre-medical students. Respondents from the high school level who plan to enroll in pre-medical programs can be included in future revisions of the instrument to assess their readiness for college chemistry courses. In addition, several items exhibited similar item difficulties and may require deletion in future test versions, as they may not be useful for objective measurement. However, deleting these items should not decrease the research instrument's quality and construct validity. Lastly, items related to introductory biochemistry topics may also be included in future versions of the research instrument. Including introductory biochemistry topics in the roster of items in the research instrument may also aid in the assessment of students' readiness to learn biochemistry concepts. Biochemistry is a pre-requisite course that follows the general chemistry and general organic chemistry courses in pre-medical programs.

CONCLUSIONS

The *Prior Knowledge of Chemistry Concepts Test* exhibited adequate psychometric properties along the Rasch measurement framework, supporting its construct validity and reliability. The research instrument has the potential to be utilized as a diagnostic tool that measures pre-medical students' knowledge of general chemistry and general organic chemistry. Using the research instrument during assessment and evaluation promotes the alignment of program outcomes to the learning outcomes in pre-requisite chemistry courses. In addition, the research instrument can also guide chemistry educators in designing strategies to improve pre-medical students' conceptual knowledge of essential chemistry concepts that are relevant to their future professional practice. Future research can further enhance the test and expand the applications to measure the prior knowledge of high school students who plan to enroll in pre-medical programs.

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