Path Analysis of Critical Thinking in Chemistry among Health Science Students Informed by the Rasch Measurement Framework

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Abstract. Critical thinking in chemistry is a crucial competency for health science students, as it is linked to evidence-based decision-making and the application of chemical knowledge in clinical and health-related contexts. However, limited empirical work has examined, using Rasch measurement models, how specific chemistry-related cognitive characteristics jointly contribute to the development of critical thinking. This study proposes and tests a theoretically informed path model explaining critical thinking in chemistry among health science students by applying a Rasch measurement framework. Data were collected from 577 second-year health science students enrolled in prerequisite chemistry courses in a Philippine tertiary institution. Four Rasch-validated instruments were employed to measure prior chemistry knowledge, knowledge of visual representations, chemical identity thinking, and critical thinking in chemistry. Dichotomous and rating scale Rasch models were applied to obtain interval-level person ability measures or logits, ensuring measurement invariance and suitability for structural modeling. Path analysis using Rasch-derived measures exhibited excellent model fit and revealed that chemical identity thinking was the strongest direct predictor of critical thinking in chemistry, followed by prior chemistry knowledge and visual representation knowledge. Moreover, prior chemistry knowledge partially mediated the relationship between chemical identity thinking and critical thinking, while a significant serial mediation effect was observed through prior chemistry knowledge and visual representation knowledge. The model explained 18% of the variance in health science students' critical thinking in chemistry, indicating that there are other cognitive and non-cognitive factors that should be considered.

Keywords: Chemical identity thinking, Critical thinking in chemistry, Knowledge of chemistry concepts, Path analysis, Rasch model, Visual representations in chemistry.

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1 Introduction

Critical thinking is one of the most desired cognitive skills that health science students should possess prior to becoming health professionals. Aside from its role in clinical reasoning [1], critical thinking is crucial in delivering quality, evidence-based care to patients [2, 3]. Critical thinking is often described as a set of cognitive skills that are anchored in higher-order thinking skills. In the Delphi report, critical thinking was defined as 'purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based' [4]. Health science students therefore should be able to analyze complex information and provide judgment that is situated in the context. A recent update frames critical thinking as a metacognitive process that consists of a number of sub-skills (e.g., analysis, evaluation, and inference as core skills of critical thinking) and dispositions [5, 6]. Based on these definitions, critical thinking is a complex and advanced cognitive construct that goes beyond logical reasoning to reflect upon the premises, concepts, assumptions, and methods that increase the chance of generating a logical conclusion.

In this study, critical thinking in chemistry was drafted based on the notion that critical thinking is context-specific. In prerequisite chemistry courses, critical thinking is commonly applied in studying reaction mechanisms or in performing analyses of chemical data. However, the transition towards applying chemistry concepts to health contexts is guided by the difference between in vitro chemical systems and chemical environments in physiologic systems [7]. Hence, critical thinking in chemistry shifts from understanding chemical reactions and molecular interactions in controlled chemical environments to applying these concepts in complex systems that influence health and well-being. A successful application of chemistry concepts to health concepts requires critical thinking within chemistry contexts, then applying the concepts to health-related contexts. In this study, critical thinking in chemistry was defined as the ability to make correct decisions based on correct evaluation of chemical information using causal-mechanistic reasoning.

Chemistry concepts involve information from the submicroscopic, symbolic, and macroscopic domains. The ability of a health science student to link the domains can be developed by promoting mechanistic reasoning, as this type of reasoning requires the cognitive skills that are associated with critical thinking. It is desired for prerequisite chemistry courses to develop the critical thinking of health science students in selected chemistry concepts that are relevant to clinical practice because prerequisite chemistry courses provide conceptual scaffolds that serve as anchors for more sophisticated chemical reasoning that is anchored in health-related and clinical contexts. Despite several studies focusing on the development of critical thinking in students, there is a limitation in studies that investigate the competencies that health science students must possess to foster the development of causal mechanistic reasoning, which reflects critical thinking in chemistry.

2 Literature Review

2.1 Critical Thinking in Chemistry as a Desired Skill of Health Science Students

In health science programs, science education aims to prepare students to apply science concepts to their future professional roles. Central to the application of science concepts to socio-scientific issues, such as those related to health, is critical thinking [8]. Critical thinking has been conceptualized as a set of cognitive skills and dispositions [4]. Previously, critical thinking has been widely regarded as generic, although recent research advocated that critical thinking is discipline-specific. It was highlighted that in various disciplines, the common attributes of critical thinking skills include application of knowledge to new situations, recognition of complexity, evaluation of evidence, and possessing dispositions that enable critical thinking [9]. Nevertheless, critical thinking is widely known to be multidimensional [10].

In prerequisite chemistry courses in health science programs, many of the activities such as making inferences, predicting results of a chemical reaction, and explaining molecular mechanisms require critical thinking using various domains of chemistry (e.g., sub-microscopic, symbolic, and macroscopic). It is highlighted in chemistry education literature that critical thinking is involved in causal mechanistic reasoning. Nevertheless, chemistry education associates critical thinking with reasoning, application and synthesis of knowledge, and analysis [11]. A more comprehensive view of critical thinking has been based on the cognitive skills associated with science and engineering practices [12].

There is a need to determine the critical thinking of health science students in a chemistry context because it can predict how well students apply chemistry concepts in health contexts. Much has been reported on the role of critical thinking in clinical reasoning and other health-related contexts [2, 13]. For prerequisite chemistry courses in health science programs, chemistry concepts are applied in various health-related contexts [14, 15, 16]. Since the successful application of chemistry requires reasoning using various domains of chemistry (sub-microscopic, symbolic, and macroscopic), it is desired for health science students to develop critical thinking in chemistry contexts. In this study, critical thinking was anchored in causal mechanistic reasoning in selected chemistry contexts, as causal mechanistic reasoning involves cognitive skills such as explaining, rationalizing, predicting, supporting arguments, and eventually, supporting decisions within a chemistry context [17], which are related to the cognitive skills linked to critical thinking.

2.2 Prior Knowledge of Chemistry Concepts and Critical Thinking in Chemistry

Health science students' prior knowledge of chemistry concepts can foster the development of critical thinking in chemistry. Prior knowledge of chemistry concepts

serves as a foundation for cognitive activities that are related to critical thinking. In general, low prior knowledge limits learners' ability to integrate concepts and apply them in complex situations [18]. Students who enroll in college chemistry are often inexperienced with the application of critical thinking when they were in high school [19]. Chemistry subjects in the secondary level focus on preparing students for college-level chemistry education [20]. Students who pursue health science programs are also required to pass their chemistry subjects in secondary level [21]. In a recent study [22], conceptual knowledge in chemistry is linked with students' critical thinking when learning the stability of organic compounds. Moreover, it was cited that factual chemical knowledge is essential in reasoning activities related to chemistry [23]. Lastly, it was reported that prior knowledge of chemistry concepts is important when constructing explanations about chemical phenomena [24]. Therefore, health science students' prior knowledge of chemistry concepts positively influences mechanistic reasoning in chemistry contexts, which is reflective of critical thinking in chemistry.

2.3 Visual Representational Knowledge and Critical thinking in Chemistry

Visual representations in chemistry provide details on the molecular structure and features of molecules [25,26], which are necessary for inferring molecular properties [27]. As such, visual representations in chemistry serve as epistemic objects to communicate molecular interactions and the abstract nature of molecular phenomena [28]. Knowledge of visual representations in chemistry influences students' ability to infer molecular properties and molecular interactions. Visualizations act as epistemic objects that contribute to knowledge generation [29]. Given this argument, it is plausible to hypothesize that knowledge of visual representations in chemistry positively influences students' knowledge of chemistry concepts. In one study, knowledge of chemical representations and visualizations stimulates critical thinking as representations help in the long-term storage of information [30]. In addition, the utilization of external chemical representations also facilitates reasoning in chemistry contexts [27]. These studies support the notion that knowledge of visual representations in chemistry positively influences causal mechanistic reasoning in chemistry, which is a direct indicator of critical thinking in chemistry. Therefore, health science students' knowledge of visual representations in chemistry positively influences knowledge of chemistry concepts and critical thinking in chemistry.

2.4 Chemical Identity Thinking and Critical Thinking in Chemistry

The term chemical identity was described as an "*attribute of a substance which makes it different from other substances*" [31]. As a part of the chemical thinking framework, chemical identity thinking is concerned with answering the question "what is this substance" [32]. Chemical identity thinking follows a progression or sophistication of reasoning, from *objectivization*, *principlism*, *compositionism*, and *interactionism* [31]. The most advanced level of chemical identity thinking (interactionism) relates to the analysis of molecular interactions to describe the properties of substances [33]. Such a

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 [34, 35].

2.5 Rasch Analysis in Path Analysis

The Rasch model was 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 [36]. 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 [37], and the differences between any two consecutive raw scores cannot be assumed to represent equal intervals [38]. In addition, the sum of raw scores of various research instruments cannot be used to compare student performance because item difficulties are different in each research instrument [39]. Subjecting non-linear measures to statistical tests also produces distorted results [37]. Rasch theory serves as a guide in formulating an instrument that represents a range of "test-item difficulty" to its respondents [39]. Through the use of Rasch analysis, validated instruments can be developed to evaluate the effectiveness of a curriculum and the learning progress of students [40]. 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. Based on the literature review, this study aims to propose and test a path model that explains how critical thinking in chemistry is enhanced based on cognitive characteristics of health science students.

3 Theoretical Framework

The present study was framed using Knowledge Integration Theory, given that chemistry concepts involve several types of information from the submicroscopic, symbolic, and macroscopic domains. Knowledge Integration Theory posits that students' cognitive activities involve the linking of multiple, diverse, and often contradicting ideas in explaining scientific phenomena [41, 42]. Knowledge integration is crucial in supporting students' reasoning [43], allowing students to elicit and connect scientific ideas successfully [42]. Causal mechanistic reasoning in chemistry, which is reflective of cognitive skills associated with critical thinking, involves knowledge integration across multiple concepts simultaneously. However, performing this cognitive feat is inherently challenging because it involves complex reasoning involving the analysis of various characteristics and behaviors of chemical entities [17]. Furthermore, causal-mechanistic reasoning involves explaining how and why a chemical phenomenon occurs [44].

This study aimed to describe how health science students who are enrolled in prerequisite chemistry courses explain chemistry concepts. While it is desired for health

science students to apply chemistry concepts to health-related and professional contexts [7, 15, 16], it is necessary for students to develop critical thinking in chemistry to promote conceptual coherence in specific contexts, especially since observed chemical reactions in prerequisite chemistry courses are approached by using in vitro chemical environments. Fostering critical thinking in chemistry also prepares students to integrate multiple concepts in explaining or predicting chemical observations in in vivo chemical environments [15]. In this study, three variables have been hypothesized to influence critical thinking in chemistry: prior knowledge of chemistry concepts, knowledge of visual representations, and chemical identity thinking.

4 Aims and Hypotheses

Drawing on data collected from health science students enrolled in a tertiary institution in Cordillera Administrative Region, the Philippines, a path analysis was conducted to explore the structural relationships between the following variables: critical thinking in chemistry, prior knowledge of chemistry concepts, visual representation knowledge in chemistry, and chemical identity thinking. On the basis of the review of the literature, the following hypotheses were generated:

H1: Chemical identity thinking has a positive effect on prior chemistry knowledge.
H2: Prior chemistry knowledge has a positive effect on visual representation knowledge.
H3: Prior chemistry knowledge positively predicts critical thinking in chemistry.
H4: Visual representation knowledge positively predicts critical thinking in chemistry.
H5: Chemical identity thinking has a direct positive effect on critical thinking in chemistry.
H6: Prior chemistry knowledge mediates the relationship between chemical identity thinking and critical thinking in chemistry.
H7: The relationship between chemical identity thinking and critical thinking in chemistry is serially mediated by prior chemistry knowledge and visual representation knowledge.

The hypothesized path model is illustrated in Figure 1.

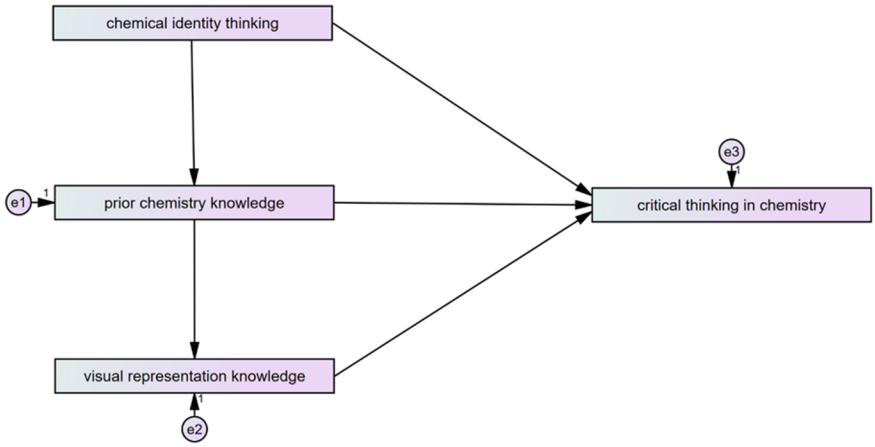


Fig. 1. Hypothesized path model

5 Methods

5.1 Participants

The participants of this study were second-year health science students of a tertiary educational institution in Baguio City, Benguet, the Philippines. The students had completed general chemistry, general organic chemistry, and analytical chemistry, and were enrolled in a biochemistry course. A total of 577 participants answered the data-gathering tools used in this study.

5.2 Research Instruments

Four data-gathering tools were used in this study. These were the Prior Knowledge of Chemistry Concepts Test (PKCCT), Visual Representations Test in Chemistry (VRTC), Chemical Identity Thinking Instrument (CITI), and Claim Evaluation in Chemistry Test (CECT). All research instruments were validated using the Rasch measurement framework.

Prior Knowledge of Chemistry Concepts Test. The Prior Knowledge of Chemistry Concepts Test (PKCCT) was developed to assess students' foundational knowledge in selected topics from general chemistry and introductory organic chemistry (Barcelo, 2023). The instrument consists of 47 multiple-choice items, comprising 26 items anchored on general chemistry concepts and 21 items on general organic chemistry concepts. The test was designed to capture students' *conceptual knowledge of essential and relevant general chemistry and general organic chemistry in pre-medical*

programs in the Philippines. The items in the instrument reflected the chemistry concepts that are applied in health professional courses such as clinical chemistry, community and public health, and pharmacology.

Visual Representations Test in Chemistry. The Visual Representations Test in Chemistry (VRTC) was developed to measure students' knowledge about visual representations that are commonly used in prerequisite chemistry courses, such as general chemistry and general organic chemistry. The difficulty and types of items were drafted based on the hypothesized progression of conceptual knowledge of visual representations in chemistry. Briefly, the conceptualized progression was based on increasing knowledge of features of chemical representations (e.g., skeletal structures, ball and stick models, particle models) to their molecular properties. The first version of VRTC has 26 multiple-choice items composed of 4 items about particle models, 12 items about skeletal structures, 5 items related to ball and stick models, 3 items on electrostatic potential maps, and 2 items related to Newman projections. The instrument was analyzed using the dichotomous Rasch model.

In the hypothesized progression of knowledge of visual representations, Level 1 involves recognition of the explicit features of a visual representation. Level 2 requires knowledge of implicit features of the visual representation that are not directly depicted by the chemical representation. Lastly, Level 3 involves the ability to infer structure-property relationships or evaluate the equivalence of different visual representations. A student who exhibits Level 1 knowledge knows that a ball and stick model depicts atomic composition, chemical bonds, and molecular geometry, but may fail to recognize other details, such as the presence of lone pairs or bond dipoles. A student who possesses Level 2 knowledge can infer molecular properties (e.g., dipole moment) from the same model by considering atomic composition and electronegativity differences. Lastly, a student who possesses Level 3 knowledge can evaluate the equivalence of visual representations (e.g., assessing whether visual representations represent the same molecule) and use representations in predicting physical or chemical properties. Thus, students with Level 3 knowledge can apply multiple visual representations to characterize physical and chemical properties of a substance. These hypothesized levels are grounded on the expected competencies of pre-medical students who have finished pre-requisite chemistry courses such as general chemistry and general organic chemistry.

Chemical Identity Thinking Instrument. The Chemical Identity Thinking Instrument (CITI) was developed to examine students' ability to differentiate and reason about substances or materials based on their chemical identity [33], based on the framework described previously [31]. This open-ended constructed-response instrument comprises 20 items: the first part consists of 10 items in which students are asked to determine whether pairs of substances or materials are similar or different, while the second part includes 10 contextualized comparison tasks, each accompanied by explicit cues related to molecular structure (MC), properties (P), source (S), or function (F). In each item, students are required to evaluate whether two substances or materials are the same or

different and provide an explanation of why they think the substances or materials were the same or different. The answers were evaluated using a rubric, then classified into levels based on four levels of reasoning patterns: Level 1 (unsupported or inaccurate chemical identity thinking); Level 2 (chemical identity thinking based on *objectivization*); Level 3 (chemical identity thinking based on *principlism*); and Level 4 (chemical identity thinking based on *compositionism* or *interactionism*). The instrument was evaluated using a Rasch rating scale model.

Claim Evaluation in Chemistry Test. The Claim Evaluation in Chemistry Test (CECT) was designed to measure health science students' ability to make correct decisions based on correct evaluation of chemical information using causal-mechanistic reasoning. Similar to CITI, CECT is an open-ended constructed-response instrument composed of 20 items related to five themes: General Chemistry, Analytical Reasoning, Scientific Method, Conceptual Understanding, and Interdisciplinary Applications. In each item, students are tasked to evaluate a claim by choosing two options (invalid or valid), then provide an explanation to justify their answer. Using a rubric tool, students' answers were classified based on a four-level progression (Level 0, Level 1, Level 2, and Level 3). The levels were hypothesized based on an increasing ability to choose a correct claim and justify the claim with correct explanations that are anchored in causal mechanistic reasoning. This instrument was analyzed using the Rasch partial credit model.

Students who exhibit Level 0 critical thinking in chemistry are unable to identify a correct claim and fail to provide explanations grounded in causal–mechanistic reasoning. At this level, responses are often characterized by unrelated or fragmented explanations, the presence of misconceptions, or the absence of any justification for the selected claim. Level 1 critical thinking is demonstrated when students are able to select a correct claim but cannot support it using causal–mechanistic reasoning. In some cases, students at this level may present a correct explanation despite selecting an incorrect claim, reflecting partial conceptual understanding. Students who can select a correct claim but provide only incomplete or superficial causal–mechanistic explanations are classified as exhibiting Level 2 critical thinking. At both Levels 1 and 2, reasoning is commonly heuristic or principle-based rather than mechanistic. In contrast, students who exhibit Level 3 critical thinking are able to correctly identify an appropriate claim and justify it using coherent and scientifically accurate causal–mechanistic reasoning. These students demonstrate the ability to integrate chemical concepts to explain how and why a phenomenon occurs. A summary of the characteristics of all research instruments is presented in Table 1.

Table 1. Characteristics of research instruments.

Instrument	Construct	Items	Rasch Model	Progression-based
PKCCT	Prior chemistry knowledge	47	dichotomous	No
VRTC	Visual representation knowledge	26	dichotomous	Yes
CITI	Chemical identity thinking	20	rating scale	Yes
CECT	Critical thinking in chemistry (Operationalized as causal-mechanistic reasoning)	20	partial credit	Yes

5.3 Data Analysis

In each research instrument, the raw data were analysed using WINSTEPS 5.9.0 to obtain the Rasch student measures. The dichotomous Rasch model was applied in PKCCT and VRTC; the Rasch rating scale model was used for CITI; and the partial credit model was used for CECT. Path analysis was used to examine the direct and indirect relationships among observed variables. Path analysis, an observational technique [45], was used to estimate the magnitude and significance of the direct and indirect theoretically hypothesized relationships among variables such as prior knowledge of chemistry concepts, visual representational knowledge, and chemical identity thinking on critical thinking in chemistry.

Two hypothesized models were developed based on the literature review and the theoretical framework. In these models, chemical identity thinking was used as an exogenous variable; prior chemistry knowledge and visual representation knowledge were treated as mediating or endogenous variables; and critical thinking is the final endogenous outcome variable. The path model presents a streamlined and hierarchical structure, wherein chemical identity thinking functions as an upstream construct influencing prior chemistry knowledge, which in turn predicts visual representation knowledge, with all three variables contributing directly to critical thinking in chemistry. This model emphasizes a sequential progression of chemistry cognition, suggesting that higher-order reasoning about chemical identity organizes foundational conceptual knowledge and representational competence, which collectively support critical thinking. In another study, the authors performed path analysis using Rasch measures to explore factors that influence self-assessment intentions using scale instruments [46]. In this study, path analysis involved student measures that were obtained after performing Rasch analysis on the data from the four research instruments.

5.4 Ethical Consideration

The approved research protocol was submitted for ethics review on February 18, 2019, to the Saint Louis University Research Ethics Committee and was approved on March 25, 2019, with an ethics approval certificate SLU-REC 2019–021.

6 Results

6.1 Characteristics of Research Instruments and Suitability for Structural Modeling

The Rasch parameters reported in Table 2 provide strong evidence that all four instruments functioned adequately as measurement tools and yielded defensible person measures for subsequent path analysis. Item reliability indices ranged from 0.97 to 0.99 while item separation indices ranged from 5.27 to 10.31. These results indicate that the hierarchy of item difficulties was highly stable and the instruments could distinguish several levels or strata of item difficulty. The person reliability values were lower for PKCCT (0.67) and VRTC (0.66) and higher for CITI (0.74) and CECT (0.83). The item fit statistics across all research instruments were well within acceptable Rasch criteria, with infit and outfit mean-square values clustering around 1.00 and standardized fit statistics largely between −2 and +2. This indicates that the items conformed to the expectations of the Rasch model and contributed meaningfully to the measurement of a single dominant latent trait in each instrument. This interpretation is further supported by the low unexplained variance in the first contrast (1.36–1.59 eigenvalue units), satisfying commonly accepted unidimensionality criteria. These findings justify the use of Rasch-derived logits as interval-level measures in the subsequent correlation and path analyses.

Table 2. Rasch characteristics of research instruments.

Rasch Parameters	PKCCT	VRTC	CITI	CECT
Person Reliability	0.67	0.66	0.74	0.83
Item Reliability	0.99	0.98	0.97	0.99
Person Separation	1.42	1.41	1.68	2.18
Item Separation	8.40	7.90	5.27	10.31
Item Difficulty	-2.19 to 1.39	-1.84 to 1.25	-0.65 to 0.35	-1.23 to 0.71
Item Infit MNSQ	0.96 to 1.05	0.94 to 1.09	0.90 to 1.08	0.89 to 1.09
Item Infit ZSTD	-1.32 to 1.64	-1.32 to 2.81	-1.82 to 1.39	-2.24 to 1.53
Item Outfit MNSQ	0.95 to 1.08	0.91 to 1.13	0.89 to 1.08	0.90 to 1.10
Item Outfit ZSTD	-1.60 to 1.66	-1.36 to 2.82	-1.91 to 1.31	-1.80 to 1.66
Point Measure Correlation	0.14 to 0.32	0.23 to 0.38	0.35 to 0.48	0.44 to 0.56
Unexplained variance of 1st contrast	1.59	1.46	1.36	1.36
Largest standardized correlation	-0.15	-0.19	-0.17	-0.16

6.2 Correlation of variables

The descriptive statistics in Table 3 show that mean person measures for all constructs were near zero logit, reflecting the relative difficulty of the instruments with respect to the sampled cohort. The wider standard deviation observed for visual representation knowledge (SD = 0.83) suggests greater variability in students' representational competence compared with prior chemistry knowledge and chemical identity thinking. This variability may reflect differences in instructional exposure to advanced representational forms (e.g., electrostatic potential maps, Newman projections), which are not uniformly emphasized across chemistry courses. All bivariate correlations among prior chemistry knowledge, visual representation knowledge, chemical identity thinking, and critical thinking in chemistry were statistically significant and positive. The strongest association was observed between chemical identity thinking and critical thinking in chemistry (r = 0.328), followed by prior chemistry knowledge and critical thinking (r = 0.308). These relationships suggest that higher-order reasoning about substance identity is more closely aligned with critical thinking performance than mere possession of factual or representational knowledge. From a Rasch-informed perspective, these correlations are particularly meaningful because they are based on

logit measures that are sample- and item-independent, rather than raw scores. Thus, the observed relationships more accurately reflect associations among latent traits rather than artifacts of test difficulty or score distributions. The modest but consistent correlations support the plausibility of a mediated structural model rather than a simplistic direct-effects framework.

Table 3. Descriptive statistics and correlations of the study variables.

Variable	PCK	VRK	CIT	CTC
Prior chemistry knowledge (PCK)				
Visual representation knowledge (VRK)	.279**			
Chemical identity thinking (CIT)	.264**	.113**		
Critical thinking in chemistry (CTC)	.308**	.233**	.328**	
Minimum	-1.77	-4.71	-2.92	-3.39
Maximum	2.34	2.19	2.12	1.78
Mean	-0.08	-0.34	0.04	-0.57
Standard deviation	0.57	0.83	0.61	0.79
Skewness	0.135	-0.346	-0.136	-0.090
Kurtosis	0.532	-0.090	1.355	0.279

Note: PCK = prior chemistry knowledge; VRK = visual representation knowledge; CIT = chemical identity thinking; CTC = critical thinking in chemistry

6.3 Primary Analysis

The path model demonstrated adequate model fit: χ^2=1.038, p=0.308, comparative fit index (CFI) = 1.000, goodness of fit index (GFI)=0.999, adjusted goodness of fit index (AGFI)=0.911, and root-mean-square error of approximation (RMSEA)=0.008.

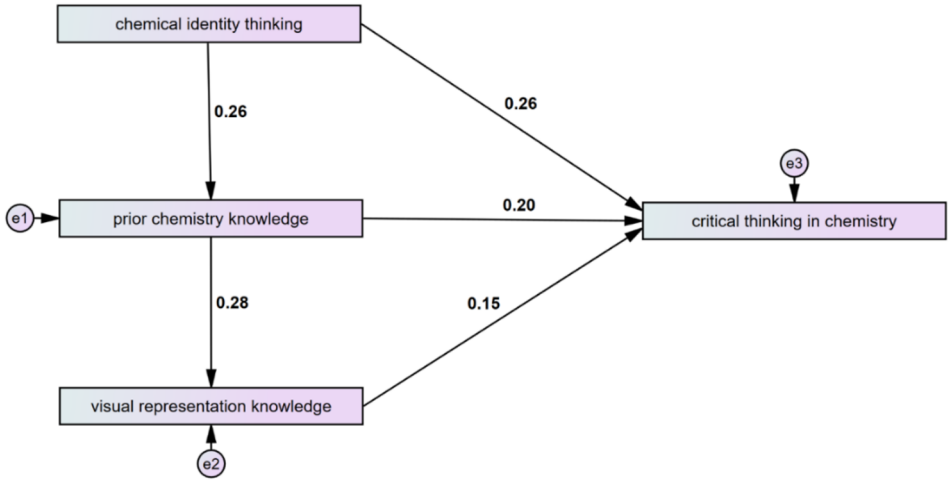


Fig. 2. Path analysis model showing the standardized parameter estimates

As shown in Table 4, all hypothesized paths in the final model were positive and statistically meaningful, with chemical identity thinking emerging as the strongest direct predictor of critical thinking in chemistry, followed by prior chemistry knowledge (β = 0.198) and visual representation knowledge (β = 0.149). Based on the results, CTC goes up by 0.259 standard deviations if CIT increases by 1 standard deviation. When PCK goes up by 1 standard deviation, CTC goes up by 0.198 standard deviations. Lastly, CTC goes up by 0.149 standard deviations when VRK goes up by 1 standard deviation. Chemical identity thinking also significantly predicted prior chemistry knowledge. As CIT increases by 1 standard deviation, PCK increases by 0.264 standard deviations, while PCK predicted visual representation knowledge. When PCK goes up by 1 standard deviation, VRK goes up by 0.279 standard deviations. Additionally, the model indicates a sequential and theoretically coherent structure among the constructs.

Table 4. Maximum likelihood parameter estimates for path model 2.

Model Path	Unstandardized Coefficient	Standard Error	Standardized Coefficient
CIT → PCK	0.249	0.038	0.264
PCK → VRK	0.405	0.058	0.279
PCK → CTC	0.275	0.056	0.198
CIT → CTC	0.338	0.051	0.259
VRK → CTC	0.142	0.038	0.149

Table 5 further shows that the influence of chemical identity thinking on critical thinking has additional indirect effects mediated through prior chemistry knowledge and visual representation knowledge, resulting in the largest total effect (β = 0.322).

Similarly, prior chemistry knowledge exerted both direct and indirect effects on critical thinking (total β = 0.240), whereas visual representation knowledge contributed exclusively through a direct pathway. Taken together, these results indicate that critical thinking in chemistry is best explained by a layered cognitive structure in which higher-order reasoning about chemical identity organizes foundational knowledge and representational competence, thereby supporting complex, causal–mechanistic reasoning in chemistry contexts. This pattern underscores the value of Rasch-calibrated measures in revealing both direct and mediated pathways among latent constructs.

Table 5. Standardized direct, indirect, and total effects in the path model.

Exogenous Variable	Effects	Estimates	Significance
CIT	Direct (CIT → CTC)	0.259	0.001
	Indirect (CIT →PCK→CTC)	0.052	0.001
	Indirect (CIT →PCK →VRK →CTC)	0.011	0.001
	Total	0.322	0.001
PCK	Direct (PCK →CTC)	0.198	0.001
	Indirect (PCK →VRK →CTC)	0.042	0.001
	Total	0.240	0.001
VRK	Direct (VRK →CTC)	0.149	0.001
	Indirect	-	
	Total	0.149	0.001

7 Discussion

In this study, the predictors of critical thinking in chemistry among health science students were examined. To address this inquiry, a path analysis model was proposed using the student ability logits obtained from performing Rasch analysis of the data set. The results supported the hypotheses; that is, health science students' critical thinking in chemistry can be predicted by chemical identity thinking, prior knowledge of chemistry concepts, and knowledge of visual representations in chemistry. Furthermore, the study provides evidence that prior chemistry knowledge mediates the relationship between chemical identity thinking and critical thinking in chemistry, and the relationship between chemical identity thinking and critical thinking in chemistry is serially mediated by prior chemistry knowledge and visual representation knowledge.

In the path model, chemical identity thinking was established to be the main predictor of critical thinking in chemistry. This model is consistent with contemporary views of chemistry learning as a process of knowledge integration, where higher-order reasoning about substance identity organizes and activates lower-level competencies, such as knowledge of chemistry concepts and knowledge of visual representations in chemistry. The path model conceptualizes chemical identity thinking as a cognitive organizer that supports the meaningful use of conceptual and representational

knowledge. This interpretation aligns with chemistry education literature emphasizing that students must move beyond surface-level recognition of substances toward principled reasoning about composition, structure, interactions, and function. Chemical identity thinking guides reasoning and decision-making in chemistry because it fosters the analysis of composition and molecular interactions of substances [31].

Characterizing the chemical identity of a substance engages health science students in cognitive processes that involve analysis, evaluation, and synthesis that foster causal mechanistic reasoning in various chemistry contexts. Specifically, eliciting reasoning patterns related to *interactionism* recognizes the complexity of chemical systems [31], thereby eliciting causal mechanistic reasoning. Lastly, chemical identity thinking encourages students to distinguish between what something appears to be and what it is chemically, which supports evaluative and inferential reasoning [35]. As learners move from identifying substances based on surface features to interpreting evidence like solubility, boiling point, and reactivity, they begin to construct scientifically meaningful classifications. Developing this capacity enhances their ability to form explanations and make predictions, which are core components of critical thinking in chemistry [47].

Prior knowledge of chemistry concepts, including foundational chemistry concepts and reasoning skills, is also crucial to cultivating critical thinking in chemistry contexts. Students with strong backgrounds in proportional reasoning, logic, and an understanding of chemical misconceptions tend to engage more deeply with complex chemical problems [48]. Research shows that integrating prior knowledge with frameworks such as learning progressions that emphasize chemical thinking leads to better abstraction and knowledge transfer [34]. These approaches help students connect atomic-level representations to macroscopic phenomena, enhancing their ability to critique claims, analyze data, and design experiments. Without such a foundation, students are more likely to rely on heuristics rather than scientific reasoning, limiting their capacity for critical engagement with chemical problems [19]. Hence, it is desired for health science students to possess adequate knowledge of chemistry concepts if they are expected to exhibit critical thinking in chemistry and apply such reasoning in health-related or clinical contexts.

There are two interesting findings in this study. First, it was found that there is a mediating effect of prior chemical knowledge on critical thinking in chemistry. Second, prior knowledge of chemistry concepts and knowledge of visual representations contribute to critical thinking in chemistry through serial mediation. The results indicate that a foundational knowledge of chemical identity supports the integration of chemical information from chemical representations and chemistry concepts that are learned in prerequisite chemistry courses, thereby supporting causal mechanistic reasoning in chemistry contexts. Specifically, students' knowledge of visual representations is essential in developing representational competence, or the ability to switch and utilize various types of representations [49]. Interestingly, there is a reciprocal relationship between general knowledge of chemistry and representational competence [50]. The

path model confirms that prior knowledge of chemistry concepts also influences health science students' knowledge of various visual representations in chemistry. By integrating chemical identity thinking, prior knowledge of chemistry concepts, and knowledge of visual representations in chemistry, the reasoning pattern of students becomes more grounded in attempting to link sub-microscopic and symbolic chemical information.

8 Conclusion

In summary, the results in this paper contribute to bridging the knowledge gap related to the predictors of critical thinking in chemistry among health science students. This study proposed a path model that describes how health science students can achieve critical thinking in chemistry, which is reflected in their ability to use causal mechanistic reasoning in selected chemistry contexts. The findings support a model of chemistry cognition in which reasoning about chemical identity organizes conceptual and representational competencies, enabling causal mechanistic reasoning in chemistry contexts. The study also illustrates the value of Rasch analysis in deriving objective measures of constructs for explanatory modeling, strengthening the validity of inferences drawn from structural analyses in chemistry education research.

9 Limitations

There are several limitations of this study. First, the study employed a cross-sectional design, restricting causal inferences among the modeled variables. Although the path analysis was theoretically grounded and demonstrated excellent model fit, the directionality of the relationships cannot be interpreted as causal without longitudinal or experimental validation. Second, the sample consisted of health science students from a single tertiary institution in the Philippines, which may limit the generalizability of the findings to other educational contexts, disciplines, or cultural settings. Replication across institutions and curricular structures is therefore warranted. From a measurement perspective, the person reliability was relatively lower for prior chemistry knowledge and visual representation knowledge, suggesting limited discrimination among respondents at certain ability levels. This may have attenuated some structural relationships in the model. In addition, the path model focused exclusively on cognitive variables and did not incorporate affective, instructional, or contextual factors such as motivation, teaching strategies, or curriculum alignment. Lastly, the use of Rasch-derived person measures assumes adequate model-data fit and local independence within each instrument. Violations of these assumptions could influence the stability of the estimated path coefficients. Future studies should extend the model using longitudinal designs, multi-group analyses, and additional theoretically relevant constructs to further validate and refine the proposed cognitive structure underlying critical thinking in chemistry.

10 Implications

The findings have important implications for chemistry instruction in pre-requisite chemistry courses in health science programs. Pedagogical approaches should explicitly cultivate chemical identity thinking, as it functions as a cognitive organizer for conceptual knowledge and representational knowledge in chemistry. Emphasizing the relationships among structure, property, function, and interaction in reasoning may strengthen students' capacity for causal mechanistic reasoning. Pre-requisite chemistry courses should also intentionally scaffold visual representational competence alongside conceptual knowledge to support critical thinking development. From a methodological perspective, this study highlights the strengths of Rasch-calibrated measures in path modeling, thereby ensuring measurement invariance and objective interpretability of relationships among latent cognitive constructs that are relevant in chemistry education research.

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