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Characterizing 4C Skills of Pre-Service Chemistry Teachers Through Inquiry-Based Learning with Multiple Representations (IBL-MR): Rasch Model Analysis

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ABSTRACT

21st-century education requires the development of 4C skills, namely critical thinking, communication, collaboration, and creativity, especially for prospective chemistry teachers. The purpose of this study was to characterize the profile of students' 4C skills after participating in the Inquiry-Based Learning Multiple Representation (IBL-MR) model designed to promote deep learning. The IBL-MR model emphasizes conceptual understanding through scientific inquiry activities and the integration of multiple representations into chemistry instruction. The subjects of the study were 30 first-year students in the chemistry teacher education program at UIN Walisongo Semarang, selected using a purposive sampling technique. This instrument was developed based on the 4C skill indicators that were valid and reliable. Analysis of the profile of pre-service chemistry using the Rasch model with Winsteps software. The results showed that collaboration skills had the highest achievement (+0.54 logit), followed by critical thinking (+0.32 logit) and communication (+0.12 logit), while creative thinking showed the lowest achievement (–0.18 logit). Wright Map analysis and person-item fit also showed significant variation in ability between individuals. These findings indicate that the IBL-MR strategy is effective in developing most of the 4C skills, but specific reinforcement for creative thinking and communication aspects is still needed through more exploratory and reflective pedagogical interventions.

Keywords: 4C skills; critical thinking; communication; collaboration; creativity; inquiry-based learning multiple representations; deep learning

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INTRODUCTION

Education in the 21st century faces major challenges due to rapid globalization (Tagunova et al., 2021), the industrial revolution from Industry 4.0 to Industry 5.0 (Mupaikwa, 2025), and the shift toward a knowledge-based society in the era of Society 5.0 (Habash, 2022). This condition is very urgent because these institutions have not yet delivered in an integrated manner, but also developed critical thinking, creativity, communication, and collaboration competencies to enable people to adapt to complexity in time and innovation (Seema, 2024).

The skills of the 21st century are referred to as the 4Cs (critical thinking, creativity, communication, and collaboration) (Rotherham & Willingham, 2010). These 4C skills are core competencies that must be possessed by pre-service teachers to accommodate the dynamics of 21st century learning which demands flexibility and innovation (Binkley et al., 2012). As agents of change in the world of education, pre-service teachers must be equipped with the 4C skills to design meaningful learning, empower students, and be relevant to future demands (Frerejean et al., 2021).

Pre-service chemistry education teachers in higher education are expected to possess both memorization and procedural competencies as foundational cognitive skills. These abilities align with the concept of surface learning, which encompasses recalling information, responding promptly to examination questions, and assimilating concise instructional content (Biggs et al., 2022). In contrast to this, deep learning emphasizes the ability to analyze information, think critically, think creatively, communicate, and coordinate (Entwistle, 2017). Therefore, deep learning is important for pre-service teachers as an effort to prepare teachers who not only understand content but can also be an inspiration for students (Darling-Hammond & Bransford, 2007).

In the era of 21st century learning, the deep learning approach is increasingly relevant, this is because deep learning can train critical thinking skills, creative thinking, and problem-solving skills. Deep meaningful learning not only emphasizes mastery of information but also builds students' abilities in constructing meaning, understanding patterns and understanding concepts (Mystakidis, 2021). Furthermore, in a study conducted by Cao & Sun (2024), it was found that deep learning can stimulate students to be more initiative in learning. This certainly has a positive impact on learning achievement. The deep learning approach also plays a role in improving skills to communicate knowledge both verbally and through written communication (Andrews et al., 2020).

The results of field studies show that chemistry learning is still carried out with an emphasis on (Muteti et al., 2021). In fact, chemistry learning should also emphasize in-depth conceptual learning (Holmes et al., 2015). In learning, students are asked to remember definitions, work on problems (Parchmann et al., 2015) and follow the step-by-step directions from the practical instructions (van Brederode et al., 2020). This makes it even more difficult for students to build relationships between concepts (Holmes et al., 2015). Ultimately, this results in weak critical thinking, creative thinking and scientific communication skills. Therefore, a transformation is needed in chemistry learning that is more integrative and innovative to encourage in-depth understanding and develop 21st century skills.

One of the learning strategies that can hone 21st century skills is Inquiry-Based Learning (IBL) (Bell et al., 2005). This strategy encourages students to understand concepts in depth and also trains students to think like scientists through the process of scientific investigation. Pedaste et al. (2015) stated that the inquiry strategy is based on the assumption that learning activities will become more meaningful if students are directly involved in discovering information and knowledge. Students do not only receive information from lecturers or facilitators. Pedaste et al. (2015) formulated systematic stages in IBL, namely orientation, formulating questions, designing investigations, conducting experiments, analyzing data, and concluding and communicating the results. Meanwhile, according to (Bell et al., 2005), the IBL stages start from exploring problems, developing hypotheses, and using data as a basis for drawing conclusions. Furthermore, according to Prince & Felder (2006), the stages of IBL begin with identifying a problem, developing a research question, designing an experiment, and critically reflecting on the results. In the context of higher education, IBL also aligns with the principles of active learning and student-centered learning, where students have greater control over their own learning process. This supports the development of independent, collaborative, and reflective student character.

This stage in IBL hones students' skills in connecting scientific knowledge with everyday phenomena. The problems discussed are contextual and challenging, motivating students to reason and think creatively (Zion & Mendelovici, 2012). Overall, IBL is a holistic learning approach, which not only emphasizes learning outcomes, but also the process of scientific thinking and the formation of scientific attitudes (Khalaf & Mohammed Zin, 2018). Through systematic and reflective stages of inquiry, students are encouraged to become active learners who are able to develop 21st century skills, including critical thinking, collaboration, communication, and creativity (Qablan et al., 2024). Therefore, IBL is considered an effective strategy to be implemented in chemistry learning in higher education, especially for prospective student teachers who will also become learning agents who encourage students to think scientifically.

The effectiveness of IBL in developing 4C skills is maximized by integrating various representations, which provide a concrete foundation for building students' conceptual understanding and developing their critical thinking. In chemistry, students need to master various chemical representations to explain chemical phenomena and gain a deeper understanding of the concepts. Representations in chemistry can be divided into three levels: the macroscopic, the submicroscopic, and the symbolic level (Gilbert & Treagust, 2009; Head et al., 2017)

According to (Gilbert & Treagust, 2009), the macroscopic level is a phenomenon experienced directly through the senses. Macroscopic representations include empirical properties such as mass, temperature, concentration, color, and pH, which can be measured or observed in experiments or everyday life. Submicroscopic representations are visualizations and models of small particles such as atoms, ions, and molecules, and their interactions, to explain chemical phenomena (Prokša et al., 2019). This representation is abstract and cannot be directly observed. Finally, symbolic representation includes the use of chemical formulas, reaction equations, atomic symbols, ionic notation, and graphs to describe or communicate chemical concepts concisely and systematically (Gilbert & Treagust, 2009).

The combination of IBL with multiple representation approach (IBL-MR) is predicted to be able to stimulate deep learning and form 4C skills. In this approach, the inquiry process that encourages students to actively ask questions, investigate, and draw conclusions is combined with the use of various forms of chemical representation, such as macroscopic, microscopic, and symbolic representations. Multiple representations allow students to view chemical concepts from multiple perspectives, thereby strengthening conceptual understanding (Supasorn, 2015). When students can connect the macroscopic phenomena, student observe with microscopic particles and the symbols used to describe them, students not only understand the material more deeply, but also practice their critical and creative thinking skills (Priyasmika, 2021). This process also requires students to communicate their understanding clearly and work together to solve complex problems. Thus, the application of IBL-MR in chemistry learning has great potential to create an active, collaborative, and meaningful learning environment that supports the development of 21st-century skills.

While the IBL-MR approach holds great potential in nurturing 4C skills, there is still a lack of empirical studies that clearly illustrate how these competencies are acquired and demonstrated by pre-service chemistry teachers. The lack of empirical data on the acquisition of 4C competencies among pre-service chemistry teachers is a significant problem (Binkley et al., 2012). Although considerable attention has been paid to the mastery of 21st century competencies, research that describes the development of critical thinking, creativity, communication, and collaboration among prospective chemistry teachers is still very limited (Kereluik et al., 2013). Therefore, a study is needed that not only considers learning outcomes but also examines in depth the profile of students' 4C competencies after a specific learning process.

To conclude this understanding, a measurement approach is crucial that not only captures learning outcomes but also provides detailed insights into individual competency profiles. The Rasch model offers significant advantages in this regard. As a modern psychometric approach based on item response theory, Rasch analysis enables objective and more meaningful measurement of competencies based on constructs such as critical thinking, creativity, communication, and collaboration (Bond & Fox, 2013). Unlike traditional assessment methods, Rasch assigns personal ability and item difficulty to the same linear scale, allowing for more precise interpretation of student performance (Boone et al., 2013). This approach not only reveals students' overall competency levels but also provides diagnostic feedback on how well each item measures the intended construct. Therefore, Rasch analysis is well-suited to the effectiveness of learning models such as IBL-MR by providing empirical evidence on individual competency development and the quality of the assessment instruments used (Linacre, 2016).

Therefore, this study aims to characterize the 4C skills (critical thinking, creativity, communication, and collaboration) of prospective chemistry teachers who participated in inquiry-based learning and multiple representation learning (IBL-MR). To obtain a more objective and meaningful understanding of student profile competencies, this study used a Rasch analysis approach that allows for the simultaneous measurement of individual competencies and item quality on a single linear scale. Through this approach, it is hoped that empirical data will be obtained that will indicate the level of acquisition of 21st-century skills and the effectiveness of the IBL-MR learning model in developing these competencies.

METHOD

Research Design and Participant

This study used a quantitative descriptive design to characterize the 4Cs skills of pre-service chemistry teachers: critical thinking, creativity, communication, and collaboration (4Cs). This study used a case study approach and was conducted after the implementation of the inquiry-based IBL-MR. This study was conducted in September 2024. A total of 39 pre-service chemistry teachers enrolled in the Basic Chemistry II study program at the Faculty of Science and Technology, UIN Walisongo Semarang, participated in this study. Participants were selected through purposive sampling based on their full engagement in lecture activities and willingness to participate in the 4Cs skills assessment. The IBLMR strategy was implemented to promote active inquiry and problem-solving skills while integrating various forms of chemical representation, macroscopic, sub-microscopic, and symbolic. Each topic was taught through the structured phases of the IBL model: orientation, conceptualization, investigation, conclusion, and discussion.

Instruments and Data Collection

The 4C skills were measured using a set of assessments, consisting of open-ended essay questions. The instrument for assess critical and creative thinking skills, and observation sheets to evaluate collaboration and communication aspects. Each question item and observation indicator was designed based on the 4C domain. The instrument was validated by six experts with expertise in chemistry education and learning evaluation. Content validity was analyzed using an expert judgment approach, while empirical validity and reliability of the instrument were analyzed through the Rasch Model. The analysis results showed that all instruments had good levels of validity and reliability and were suitable for measuring students' 4C skills.

Data Analysis

The responses were analyzed using the Rasch Model with the help of Winsteps software. Rasch analysis was chosen due to its capacity to convert ordinal data into interval measures, offering more objective and diagnostic insights into students' competency levels. The analysis included item and person fit statistics to assess the consistency of student response patterns against model predictions, reliability index, and separation index for both person and item scale, and Wright map to visualize person and item alignment. This approach provided robust evidence for characterizing how each pre-service teacher demonstrated the four 21st-century skills within the context of Inquiry-based Learning Multiple Representation.

RESULT AND DISCUSSION

The IBLMR strategy encourages students to engage in activities by considering macroscopic, sub-microscopic, and symbolic aspects. These strategies, though well-established, persist as indispensable elements of educational theory and practice. Students are required to respond to a series of questions, analyze them critically, and strive to achieve the intended outcomes. The strategy is implemented starting from the orientation phase and continues throughout the learning process, demanding students' focus and sustained effort. Through this approach, students consistently utilize the student worksheet as a guide to support their learning.

The next steps are conceptualization and investigation. In the conceptualization phase, students formulate questions and hypotheses based on information from various sources, such as books and the internet. In this phase, multiple representations are also implemented to enrich conceptual understanding. Students discuss and develop hypotheses through collaborative learning. The investigation phase is carried out through experiments to test the hypotheses. In this phase, students apply critical thinking to evaluate and interpret the experimental data.

After obtaining the data, students proceed to the conclusion and discussion phases. In the conclusion phase, they logically analyze the experimental results to determine whether the data support the initial hypothesis. Group discussions aim to unify understanding and collaboratively compile reports within their teams. Students also reflect on the strengths and weaknesses of the experiment and present their findings both orally and in written form. Furthermore, students complete evaluation questions to assess their critical and creative thinking skills. Meanwhile, collaboration and communication skills are observed by an observer throughout the learning process.

Overview of 4C Skill Achievements of Preservice Chemistry Teacher Students

The measurement of the 4C skills of pre-service chemistry teachers in this study covers four main domains: critical thinking, creative thinking, collaboration, and communication. Each skill is measured using instruments tailored to the student's characteristics and the course context. Critical thinking skills are measured using 11 open-ended essay questions, creative thinking skills consist of 4 exploratory context-based questions, while collaboration and communication are each measured using observation sheets developed based on a 21st-century skills rubric. Students' answers were then scored and analyzed using the Rasch model. In the Rasch model, ordinal scales are transformed into interval scales in the form of logits, allowing the distance between scores to be compared quantitatively (Bond and Fox, 2013). As a result, data representing each respondent's ability or attitude in logits were obtained. The descriptive statistics are presented in Table 1.

Table 1. Descriptive statistics of students' 4C skills (in logit scale)

4C Skill	Mean (Logit)	Standard Deviation	Minimum Logit	Maximum Logit
Critical Thinking	+0.32	1.24	–3.95	+2.69
Creative Thinking	–0.18	1.15	–3.45	+2.71
Collaboration	+0.54	0.97	–2.47	+3.18
Communication	+0.12	1.03	–3.02	+2.67

The Rasch analysis of the four 4C skills showed that collaboration was the aspect with the highest achievement, indicated by an average logit value of +0.54. This indicates that prospective chemistry teacher students tend to have good abilities in collaborating, sharing tasks, and building effective teamwork. Conversely, creative thinking showed the lowest average logit of -0.18, reflecting that students still have difficulty in developing original ideas and thinking flexibility. Furthermore, the wide range of logit values for the four skills, ranging from very low to very high scores, indicates significant variation in ability between individuals.

Analysis of Critical Thinking Skill

Critical thinking skills are measured through a number of open-ended descriptive questions that require students to interpret, analyze, provide explanations, evaluate, and draw conclusions (Facione, 2011). The analysis results show that the average logit value is +0.32 with a standard deviation of 1.24 and a range of values from -3.95 to +2.69. This value indicates that students generally have a fairly good tendency to think critically, but there are significant differences in ability between individuals. Some students are able to convey ideas systematically and present evidence-based arguments, while others still show difficulty in identifying relevant information or drawing valid conclusions (Bond & Fox, 2013).

Analysis of the suitability of student responses in answering the critical thinking skills instrument was conducted by referring to three main indicators in the Rasch Model: outfit MNSQ, outfit ZSTD, and Point Measure Correlation (PTMEA CORR). The following students were misfits based on at least one of the three indicators showed on table 2.

Table 2. Identification of Misfitting Responses in the Critical Thinking Test

Person	Outfit MNSQ	Outfit ZSTD	PTMEA CORR	Misfit
S01	2.01	2.25	–0.06	Significant misfit: MNSQ and ZSTD values are too high, negative correlation.
S25	2.18	2.21	+0.11	Extreme misfit: Responses do not match Rasch model expectations, low correlation.
S34	2.03	2.01	+0.25	Statistical misfit: MNSQ and ZSTD are high.
S11	0.55	–1.39	0.42	Marginal overfit: Responses are too consistent or “too good.”
S32	0.48	–0.72	–0.25	Extreme overfit: Negative correlation and MNSQ is very low.
S16	1.84	2.23	+0.36	Significant misfit: MNSQ and ZSTD are high.

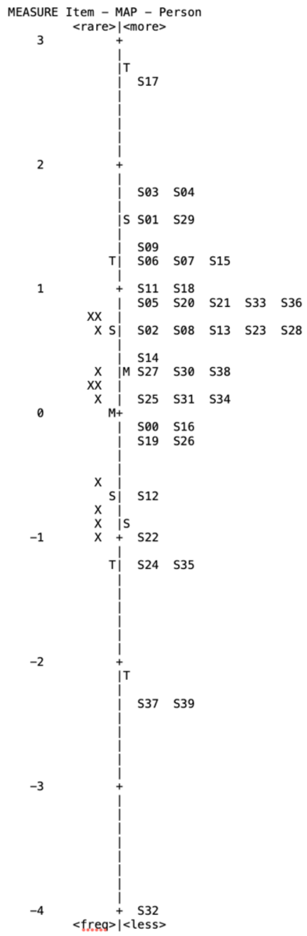

Figure 1. Wright Map of Students' Critical Thinking Skills

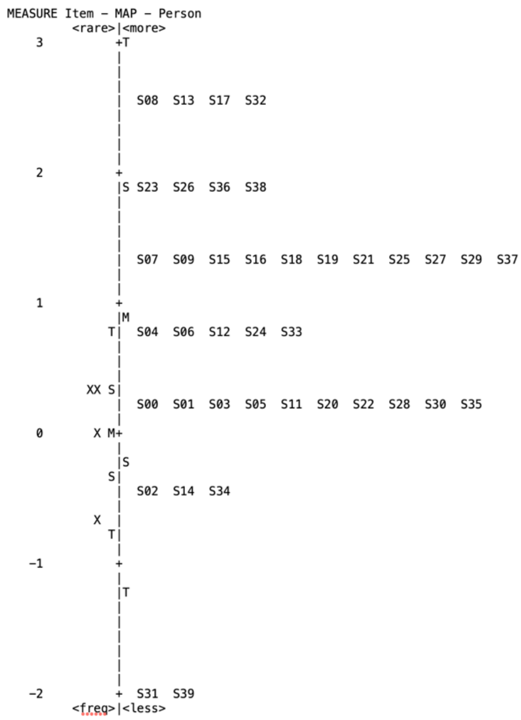

Figure 2. Wright Map of Students' Creative Thinking Skills

Most students (around 75–80%) showed a response pattern that fit the Rasch model. The students with the most deviant responses from the model were S01, S25, and S34. All three had outfit MNSQ values above 2.0, ZSTD exceeding +2.0, and very low PTMEA CORR. S01 even showed a negative correlation (–0.06), indicating that his response pattern was contrary to the model's expectations. Furthermore, S32 also showed an unusual pattern with an outfit MNSQ value below 0.5 (i.e., 0.48) and a negative correlation (–0.25), indicating that the student provided overly consistent answers, possibly without in-depth cognitive processing (overfit). Several other students, such as S16, also showed outfit MNSQ values above 1.5 and outfit ZSTDs approaching the upper limit, although their correlation values were still within a reasonable threshold. These findings indicate that although most students showed a good fit with the Rasch model, there were certain individuals whose responses could not be predicted well by the model, either due to inaccuracy, insincerity, or lack of understanding of the item content.

Furthermore, visualization using the Wright Map (Figure 1) on critical thinking skills shows a fairly wide distribution of the abilities of prospective chemistry teacher students, ranging from the highest logit of around +2.7 to the lowest logit approaching -4.0. Students at the top, such as S17, S03, S04, S01, and S29, demonstrated very high critical thinking skills. They were able to answer items with a high level of difficulty consistently, reflecting good mastery of analytical, evaluative, and conclusion-drawing skills. In the middle of the map, the majority of students fall within the logit range of +1.0 to 0, reflecting moderate critical thinking skills. Students such as S13, S14, S30, S38, and others in this group demonstrate that they are able to understand and answer items of moderate difficulty, but may still struggle with questions requiring more complex synthesis or reflective reasoning. Meanwhile, a number of students are at the bottom of the map, such as S32, S37, and S39, indicating very low critical thinking skills, with logits below -2.0. Students in this group likely have difficulty understanding the questions' requirements, drawing logical conclusions, or identifying relationships between concepts.

Analysis of Creative Thinking

Creative thinking is the ability to generate new ideas, view problems from different perspectives, and find alternative solutions (Robson & Rowe, 2012). This aspect showed the lowest mean logit, at –0.18, with a standard deviation of 1.15 and a range of –3.45 to +2.71. This negative value indicates that most students have not demonstrated optimal creative thinking skills. The following students are not fit based on at least one of the three indicators showed on table 3.

Table 3. Identification of Misfitting Responses in the Creative Thinking Test

Person	Outfit MNSQ	Outfit ZSTD	PTMEA CORR	Misfit
S16	2.35	1.94	-0.94	Extreme misfit: MNSQ is very high, and the correlation is negative.
S10	1.82	1.60	-0.94	Significant misfit: MNSQ and ZSTD are high, and the correlation is negative.
S25	1.95	0.95	-0.58	Moderate misfit: MNSQ is approaching the extreme threshold, the correlation is negative.
S01	1.65	1.03	0.47	Mild misfit: MNSQ is above the threshold of 1.5, the correlation is still quite good.
S07	1.66	1.14	0.87	Mild misfit: MNSQ is slightly above the ideal limit.

Based on the analysis of person data using the Rasch model. Approximately 56.41% of people were found to fit the Rasch model. Examples of misfit persons include five participants, namely S16, S10, S25, S01, and S07. Person S16 experienced the most extreme misfit with an outfit MNSQ value of 2.35 and a PTMEA CORR of -0.94, indicating answers that deviated significantly from the predictive model. S10 also included severe misfit due to the combination of a high outfit MNSQ (1.82), significant outfit ZSTD (1.60), and a negative correlation (-0.94). S25 showed statistical misfit with an outfit MNSQ of 1.95 and a negative PTMEA CORR (-0.58), although its outfit ZSTD did not exceed ±2.0. S01 showed a similar misfit pattern to S25, although its PTMEA CORR was still positive (0.47), thus categorized as mild to moderate misfit. Meanwhile, S07 is classified as a mild misfit because the outfit MNSQ value slightly exceeds the threshold (1.66), but still shows a high correlation with the items (0.87). Overall, these five individuals require further attention because their responses deviate from the pattern expected by the Rasch model.

Furthermore, the Wright map (Figure 2) shows the distribution of student abilities and item difficulty levels on the same logit scale. Most students fall within the logit range of 0 to +2, indicating that their abilities are at a moderate to high level. Students with the highest abilities are at logit +3 (such as S08, S13, S17, S32), while students with the lowest abilities are at logit -2 (S31 and S39). Most items fall around logit 0, indicating a moderate level of difficulty and are quite appropriate for the abilities of the majority of students (Bond and Fox, 2013). However, because there are students with both very high and very low abilities, it is recommended that items be developed with a wider variety of difficulty levels to more comprehensively measure abilities across the spectrum of participants (Sumintono & Widhiarso, 2015).

Analysis of Collaboration

The collaboration aspect showed the highest achievement compared to other skills, with a mean logit value of +0.54, a standard deviation of 0.97, and a range of values from –2.47 to +3.18. The chemistry teacher candidates appeared quite competent in working in groups, sharing roles, listening to others' opinions, and completing assignments cooperatively. However, there were still students with low collaborative skills, indicating the importance of providing a more active role. Identification of individuals experiencing misfit was carried out based on three main indicators in the Rasch analysis presented in Table 4.

Table 4. Identification of Misfitting Responses in Collaboration

Person	Outfit MNSQ	Outfit ZSTD	PTMEA CORR	Misfit
S08	2.08	3.08	-0.27	Extreme misfit: Very high ZSTD dan MNSQ, negative correlation
S18	2.43	4.02	-0.23	Extreme misfit: Very high ZSTD dan MNSQ, negative correlation
S39	1.48	1.55	0.15	Mild misfit: MNSQ & ZSTD > threshold, low correlation negative

Based on the results of the personal data analysis using the Rasch model, three students were found to show indications of misfit to the model, namely S08, S18, and S39. Student S08 had an outfit MNSQ value of 2.08, outfit ZSTD 3.08, and PTMEA Corr -0.27, which indicates an extreme misfit. The very high outfit ZSTD value indicates a statistically significant misfit, and the negative correlation strengthens the suspicion that the response pattern is inconsistent with the model. Similarly, S18 showed an outfit MNSQ of 2.43, outfit ZSTD 4.02, and PTMEA Corr -0.23, which is a very extreme misfit, with outfit ZSTD and outfit MNSQ values far beyond the normal limit and a negative correlation. Meanwhile, S39 showed an Outfit MNSQ of 1.48 and outfit ZSTD 1.55, slightly above the normal threshold, with a PTMEA Corr of 0.15, indicating a mild misfit. Although the correlation remains positive, the relatively high outfit MNSQ and outfit ZSTD scores indicate that the response patterns are beginning to deviate from the model. These three students require further attention to review the data quality or potential external factors such as unfamiliarity with the instrument's content or inconsistent response patterns.

The Wright Map (Figure 3) depicts the distribution of students' collaboration abilities based on their responses to the 20 instrument items. The map shows that most students are located around the logit point of 0, indicating moderate collaboration abilities. However, there are several students at high logits (e.g., S22, S26, S27) who reflect high collaboration abilities, as well as students at low logits such as S05, S01, and S32 who show relatively low collaboration abilities. This indicates that there is diversity in mastery of collaboration indicators among students. Overall, the items used appear to be quite capable of covering a large range of students' collaboration abilities. However, for students with very high or very low abilities, it is important to consider whether the instrument items adequately represent the students' ability levels.

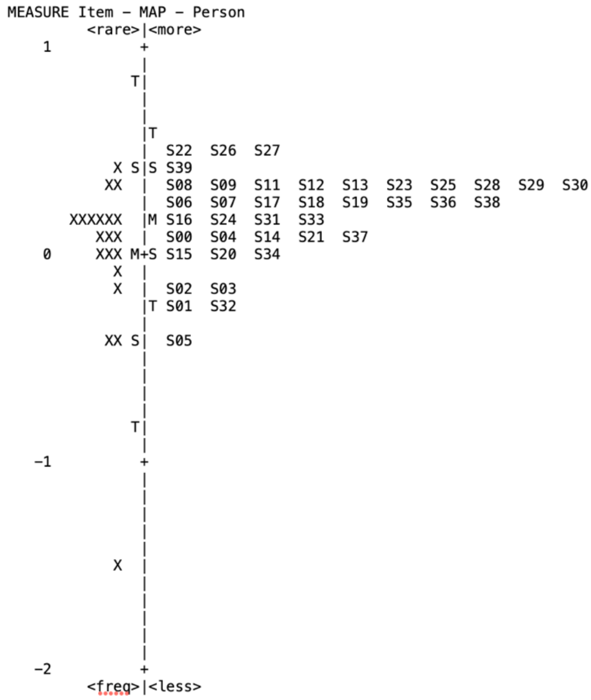

Figure 3. Wright Map of Students' Collaboration Skills

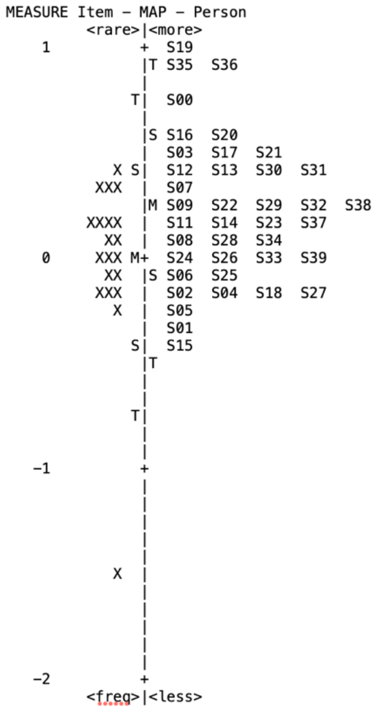

Figure 4. Wright Map of Students' Communication Skills

Analysis of Communication

Communication skills encompass students' ability to convey ideas verbally and in writing, as well as to respond appropriately to questions or arguments. The average logit score obtained was +0.12, with a standard deviation of 1.03 and a range of -3.02 to +2.67. These results indicate that students' communication skills are at a moderate level, with considerable variation. Students with high logit scores are generally able to convey ideas with clear structure and appropriate language, while students with low scores tend to be less able to convey messages effectively or experience difficulties in responding argumentatively.

Table 5. Identification of Misfitting Responses in Collaboration

Person	Outfit MNSQ	Outfit ZSTD	PTMEA CORR	Misfit
S16	1.15	0.61	–0.01	mild misfit: MNSQ and ZSTD values are within acceptable limits, negative correlation
S18	1.99	3.06	–0.14	Significant misfit: Very high MNSQ and ZSTD values, negative correlation,
S08	1.49	1.80	–0.43	Moderate misfit: Although MNSQ is still at the upper acceptable limit, negative correlation indicates

The Wright Map (Figure 4) depicts the distribution of students' communication. Most participants fall within the logit range of -0.5 to +0.5, indicating that the majority have average ability. The mean (M) positions for participants and items are quite close together, indicating that the item difficulty generally corresponds to the participants' ability. However, some participants occupy extreme positions. For example, S19 is at the highest logit position (+1), indicating very high ability, while S15, S01, and S05 are at the bottom, approaching the logit -1, indicating low ability. Interestingly, participant S18, who in the previous fit analysis showed a high misfit score, actually falls within the lower to middle ability range, indicating that her responses are inconsistent with her estimated ability. Overall, this map shows a fairly even distribution, but caution is needed for some participants who displayed extreme or non-modelled responses.

Discussion

The results of the study indicate that the IBL-MR learning strategy contributes significantly to developing the 4C skills (Critical Thinking, Creativity, Communication, and Collaboration) of preservice chemistry teachers. This strategy has been proven to be able to create active and in-depth learning that facilitates students to explore chemical phenomena through macroscopic, sub microscopic, and symbolic approaches. This is in line with the findings of (Pedaste et al., 2015; Qablan et al., 2024) stated that inquiry-based learning, when integrated with representational practices, enables learners to engage with concepts at a deeper cognitive level and develop essential 21st-century skills. The active involvement of students from the orientation phase to reflection shows that the IBL-MR approach supports stronger scientific thinking processes, communication skills, and collaboration.

However, the Rasch results show that creative thinking skills have the lowest average logit (-0.18), indicating that many students still have difficulty generating original ideas and innovative solutions. This indicates the need to strengthen active teaching strategies and explore students' creative side (Hamid, 2018). As emphasized by Beghetto & Kaufman (2014), science education is often underdeveloped due to the dominance of convergent assessment practices and lack of open-ended inquiry. Therefore, efforts are needed to develop student creativity. Conversely, the collaboration aspect recorded the highest achievement (+0.54 logit), reflecting that students were able to work together effectively in groups, share tasks, and draw conclusions. This strength indicates that IBL-MR learning successfully facilitates constructive interaction and teamwork. This is reinforced by Gillies (2016) findings, which state that structured cooperative learning environments promote not only academic achievement but also interpersonal skills that are essential for future educators. Thus, the IBL-MR strategy is not only effective in the cognitive aspect but also in developing social skills that are highly relevant for pre-service teachers in the era of collaborative learning.

Although students' critical thinking skills showed a positive mean logit value (+0.32), Rasch analysis revealed significant variation in ability. Several students showed response patterns that did not align with model expectations (misfit), such as S01 and S25, indicating potential inconsistencies in understanding or answering strategies. This phenomenon is important to observe because critical thinking is a crucial foundation in inquiry-based learning. (Facione, 2011) emphasized that critical thinking is not only a set of skills but also a habitual way of approaching problems with thoughtful analysis and reflection. Therefore, going forward, more explicit task and assessment designs are needed to systematically facilitate students' logical and evaluative reasoning.

Meanwhile, communication skills showed moderate performance with an average logit of +0.12, but some students showed a negative correlation in the statistical fit analysis, such as S08 and S15. This indicates inconsistency in conveying ideas effectively, both orally and in writing. In line with this, Vilela et al. (2025) stated that effective communication in science education requires scaffolding practices that allow students to express and refine their scientific reasoning in both oral and written forms. Therefore, the IBL-MR strategy needs to be enhanced with reflective activities such as peer feedback, scientific presentations, and class discussions to continuously develop students' scientific communication skills.

The integration of macroscopic, sub microscopic, and symbolic representations in chemistry learning has been shown to strengthen students' conceptual understanding and analytical skills. Students who are able to link the three levels of representation tend to have higher logit, especially in critical and creative thinking. This reinforces Chittleborough & Treagust (2008) argument that multiple representations help learners move from concrete experiences to abstract understanding, supporting both conceptual development and reasoning. Thus, the IBL-MR approach not only addresses the content domain but also empowers students' higher-order thinking processes in the context of chemistry.

Finally, the distribution of student abilities depicted in the Wright Map demonstrates the importance of an adaptive learning approach to student ability profiles. Students with low logits require different interventions than those with higher logits. A differentiated instruction approach is crucial in designing future IBL-MR so that all students, both low and high ability, can develop optimally. As Tomlinson (2017) stated students learn best when instruction is responsive to their readiness, interests, and learning profiles. Therefore, the results of this Rasch mapping can serve as a basis for designing more personalized and effective learning strategies.

CONCLUSION

This study aims to characterize the 21st-century skills of pre-service chemistry teacher through the application of the IBLMR strategy. This strategy encourages students' active involvement in the scientific inquiry process through the use of macroscopic, sub microscopic, and symbolic representations. The study used a quantitative descriptive approach with the participation of 39 students and instruments analyzed using the Rasch model. The results showed that collaboration was the skill with the highest achievement (+0.54 logit), followed by critical thinking (+0.32), communication (+0.12), and creative thinking as the lowest (–0.18). These findings indicate that the IBL-MR strategy is effective in creating an active and collaborative learning environment, but pedagogical reinforcement is still needed to develop students' creativity and scientific communication aspects.

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