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Development of the TTMCT Instrument and In-Depth Interview Activities to Identify Misconceptions about the Periodic Table Concept

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Abstract

Misconceptions arise when students hold ideas that conflict with scientifically accepted concepts, and persistent misconceptions can reduce learning outcomes and weaken conceptual understanding. This study analyzed students' misconceptions about the Periodic System of Elements through the development of a Three-Tier Multiple Choice Test (TTMCT) and supporting in-depth interview activities. A quantitative design was applied. Data were collected through observation, diagnostic testing, interviews, questionnaires, and documentation. Content validation involved eight experts (chemistry lecturers and chemistry teachers) and was followed by a small-scale trial to evaluate item clarity and practicality. The main study was conducted in five public and private schools and involved 250 Grade X students. TTMCT results indicated that a substantial proportion of students demonstrated misconceptions, distributed across seven distinct misconception profiles revealed by the combination of answer choice, reasoning selection, and Certainty of Response Index patterns. Interview findings helped confirm the diagnostic classifications and clarified typical reasoning used by students. Overall, the developed TTMCT instrument, complemented by in-depth interviews, proved effective for identifying and mapping misconceptions on periodic table concepts, providing diagnostic information that can guide targeted instructional remediation. Such mapping supports teachers in prioritizing concepts that require reteaching.

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INTRODUCTION

A teaching and learning process can be considered good and efficient when teachers as educators are able to identify students' levels of understanding and the sources of their misunderstanding, so that these can be used as a basis for evaluation in subsequent instruction (Nur et al., 2018). In this regard, students' levels of understanding are not merely learning outcomes, but also indicators of how students construct meaning from instruction. When students appear to "understand" yet hold alternative explanations that deviate from scientific views, learning becomes vulnerable to persistent errors that can be carried into new contexts. Such conditions underline the importance of early and accurate diagnosis, because instructional decisions will be more effective when grounded in clear evidence about what students know, what they think they know, and why their thinking takes that form.

Students' level of understanding can also indicate the presence or absence of misconceptions. Misconceptions are conceptions that conflict with those held by experts and reflect errors in interpreting relationships among variables (Indra Kartika Sari, 2021). These errors may develop when students overgeneralize everyday experiences, misapply previously learned ideas, or fail to connect symbolic representations with underlying concepts. In chemistry, misconceptions frequently occur in content that strongly emphasizes conceptual understanding, such as topics that require learners to relate microscopic-level explanations to macroscopic observations and symbolic notation (Hidayati et al., 2019). Consequently, students may successfully complete routine exercises while still holding inaccurate conceptual frameworks that hinder deeper reasoning and problem solving.

Misconceptions in chemistry, particularly in grade X chemistry content, can greatly affect students' subsequent understanding because there is relevance and interconnection among different chemistry topics (Ramadhan et al., 2020). Grade X chemistry content can be regarded as both introductory and fundamental, intended to introduce and develop students' conceptual understanding of the foundations of the broad scope of chemistry, which will later be elaborated in chemistry topics at higher grade levels. Therefore, when misconceptions occur in grade X, they have a high potential to induce further misconceptions in subsequent chemistry topics (Jusriana et al., 2022). If foundational ideas are learned inaccurately, students may struggle to integrate later concepts coherently, and instructional time can be spent remediating misunderstandings rather than extending scientific reasoning.

The Periodic Table of Elements is one of the key concepts in grade X chemistry that serves as a basic concept for understanding the characteristics and properties of elements (Susilawati, 2020). The periodic table is not only a tool for organizing information but also a conceptual framework that supports explanations about periodic trends, element reactivity, and the relationships between atomic structure and observable properties. This condition highlights the urgency of minimizing misconceptions, given that many subsequent chemistry concepts remain related to the diversity of elements. The concept of the periodic table is closely related to the concepts of chemical bonding and molecular shape (Noviani & Istiyadji, 2017). As a result, misunderstanding periodic properties, group and period meanings, or electron configuration patterns may directly disrupt students' reasoning about bond formation, polarity, and molecular geometry.

However, conceptual errors experienced by students are often overlooked by teachers or other stakeholders. This situation is unfortunate, because the periodic table is a prerequisite topic that needs to be mastered accurately in accordance with scientifically accepted concepts. When learning about the periodic table leaves traces of misconceptions in students, there is considerable potential for further misconceptions to arise in subsequent chemistry topics, and students may develop a high degree of conceptual misunderstanding (Rahmawati et al., 2019). In practice, misconceptions may persist because they are not easily detected through conventional assessments that emphasize final answers rather than reasoning. Students might select correct options by memorization or pattern recognition, while their explanations reveal fragile or incorrect understanding. Therefore, a diagnostic approach that captures both answers and reasoning is essential to reveal misconceptions that are otherwise hidden.

Identification of misconceptions needs to be carried out comprehensively, not only to determine students' levels of understanding but also to uncover the causes of these misconceptions. Misconceptions can be identified using tiered multiple choice diagnostic tests and in depth interviews (Djarwo, 2020). Tiered diagnostic tests can map misconception patterns across a wide range of concepts efficiently, while interviews allow researchers to probe how students interpret questions, justify decisions, and connect ideas. The complete set of data obtained and analysed can then be used as a basis for instructional actions so that student misconceptions can be minimized. With this combined evidence, teachers and researchers can design learning interventions that directly target the roots of students' misunderstandings rather than treating misconceptions as simple "wrong answers."

One diagnostic format that has been widely used for this purpose is the Three Tier Multiple Choice Test (TTMCT). The TTMCT is an instrument consisting of three levels. The first tier comprises multiple choice items based on the given questions. The second tier requires students to provide reasons for the answers chosen in the first tier. The third tier collects the Certainty of Response Index (CRI). The CRI indicates the degree of confidence students have in answering each question. More specifically, there are six categories that represent the scale and level of confidence in the CRI, namely total guess the answer, almost guess, not sure, sure, almost certain, and certain (Laliyo et al., 2022). By integrating confidence data, the instrument can differentiate between students who answer correctly with strong conceptual understanding and those who answer correctly due to guessing, as well as students who answer incorrectly but with high confidence—an important marker of misconception.

The TTMCT instrument has an advantage in that it is effective for measuring students' understanding. The instrument does not only consist of ordinary multiple choice items, because students are also required to justify why they selected a particular answer at the first tier (Pikoli, 2020). In this way, the second tier provides diagnostic evidence about the logic behind students' selections, while the third tier strengthens interpretation by showing how firmly students hold their ideas. These three tiers generate data that can indicate students' level of understanding and their misconception profiles regarding the periodic table concept. Furthermore, to move beyond identifying "what" misconceptions exist toward understanding "why" they occur, additional analytical and qualitative approaches are needed. The causes of students' misconceptions can be identified through Rasch model analysis and in depth interviews, enabling researchers to examine response patterns at the item and person level while also capturing students' thought processes in their own words.

Based on these considerations, this study aims to analyse misconceptions that occur in grade X students from five different schools, both public and private, through the development of a Three Tier Multiple Choice Test instrument consisting of 25 items and in depth interview activities. By combining TTMCT results, Rasch model-based evidence, and interview findings, the study is expected to provide a more comprehensive depiction of students' misconception profiles on the Periodic Table of Elements and offer actionable information that can support more targeted and effective instruction in subsequent learning.

METHODS

The method used in this study is Research and Development (R&D). Research based on Research and Development is often defined as a process or set of procedures used to develop a new product or to refine an existing product (Febriani et al., 2021). This study uses a quantitative approach because it involves a research proposal, procedures, hypotheses, fieldwork, data analysis, and careful attention to aspects of measurement, calculation, formulas, and the accuracy of numerical data. This research is structured in four stages, namely Define, Design, Develop, and Disseminate (Rahmatsyah & Dwiningsih, 2021).

The Define stage is used as the preliminary study to collect data about existing conditions (needs analysis). The Design stage involves preparing the design of the Three Tier Multiple Choice Test diagnostic instrument and supporting instruments for in depth interviews to analyse conceptual understanding, and requesting validation from expert validators. The effectiveness of the product is tested at the Develop stage to ensure that it can be used appropriately with the target group. The Disseminate stage covers publication or dissemination of the diagnostic test instrument (Three Tier Multiple Choice Test) and the supporting in depth interview instruments. The research procedure is outlined in greater detail in the flowchart presented in Figure 1.

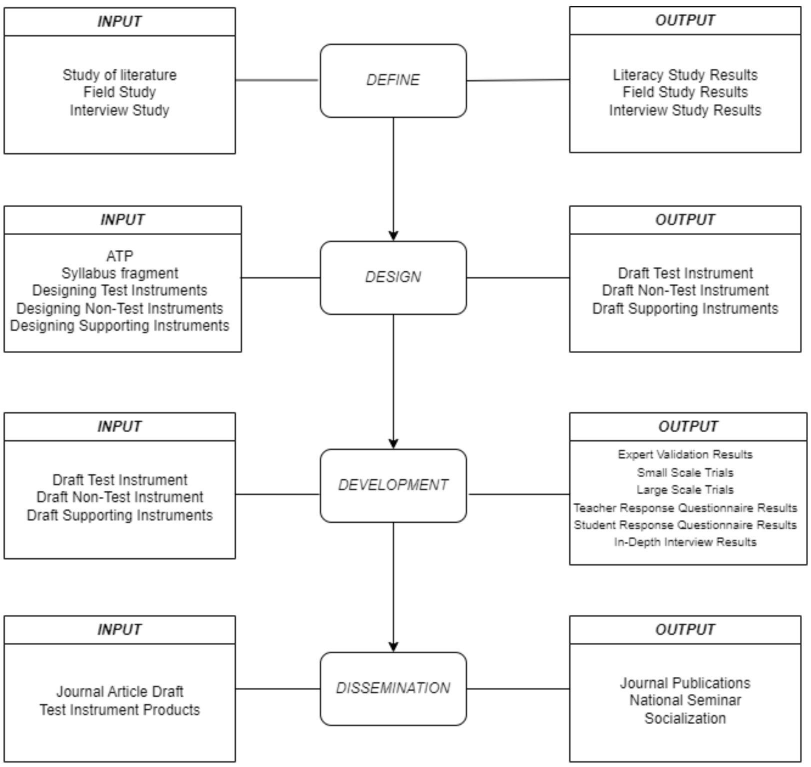

Figure 1. Research Stages

RESULT AND DISCUSSION

Define Stage

The Define stage encompasses a series of defining processes related to the requirements for development. This stage is carried out to identify problems that arise in the implementation of chemistry instruction and to collect information relevant to the needs of chemistry learning activities in the classroom, which is usually referred to as needs analysis. The first stage in this research design consists of two activities, namely a literature review and a field study. The literature review was conducted to obtain information related to the Three Tier

Multiple Choice Test (TTMCT) instrument and in depth interview activities, which constitute the main products and procedures in this research. The field study was conducted to determine the real conditions of the schools and the implementation of chemistry teaching and learning (Fetio et al., 2021).

Design Stage

The Design stage represents the second stage conducted by the researchers after completing the Define stage. This stage is carried out when information related to the final product has been collected. The Design stage consists of several activities, including the planning and preparation of the TTMCT instrument on the periodic table concept, the teacher response questionnaire, the student response questionnaire, and the guidelines for in depth interviews.

Development Stage

The Development stage follows the completion of the Design stage. This stage is carried out in order to test the product that has been developed during the Design stage. Product testing is conducted in two phases, namely expert validation and trial implementation of the TTMCT instrument together with the in depth interview activities. More specifically, the Development stage consists of two steps, namely expert appraisal and developmental testing. The expert appraisal step is a technique used to obtain suggestions for improvement from experts (Mulyani et al., 2021). Expert judgment is very important in development research so that the TTMCT instrument being developed can become more effective and tested before being used. The developmental testing step is carried out to obtain direct input in the form of responses and test results from research subjects based on their performance on the developed test instrument.

Development Stage – Small Scale Trial

The small scale trial was conducted to determine the feasibility and readability of the developed Three Tier Multiple Choice Test (TTMCT) instrument and produced data that can be considered good. Feasibility and readability were determined through content validation by experts and a small scale trial of the TTMCT instrument. Content validation was carried out by experts whose fields are relevant to the research topic, namely two chemistry lecturers from Universitas Negeri Semarang and six chemistry teachers consisting of two teachers from SMA Negeri 1 Cawas, one teacher from SMA Muhammadiyah 1 Klaten, one teacher from SMA Negeri 3 Semarang, one teacher from SMA Negeri 12 Semarang, and one teacher from SMA Karangturi Semarang. The content validation results showed an average validation score of 38.7, which indicates that the instrument is very valid and feasible to be used in the field for research purposes.

The small scale trial that was analysed through the student response questionnaire showed that 92% of students (23 out of 25 students) stated that the sentences and language used in the TTMCT instrument were easy to understand. Another aspect concerned the allocation of time for completing the test, where 84% of students (21 out of 25 students) stated that the allotted time was sufficient, while 16% of students (4 out of 25 students) stated that the time allocation felt insufficient, so they felt rushed and several items were left unanswered. The student response questionnaire in the small scale trial was also used to determine whether students felt they benefited from the TTMCT instrument, whether the developed TTMCT instrument helped them identify their areas of misunderstanding, and whether students gained additional insight after completing the test.

Results of the student response questionnaire indicated that 96% of students (24 out of 25 students) reported gaining benefits after completing the TTMCT instrument, 100% of students (25 students) stated that the administered TTMCT instrument helped them identify their areas of misunderstanding, and 100% of students (25 students) stated that they gained additional insight after completing the test. The TTMCT instrument that was developed and tested in the small scale trial demonstrated good reliability, with a Person Reliability value of 0.83, an Item Reliability value of 0.75, and a Cronbach's Alpha of 0.88. Detailed reliability and validity results of the TTMCT instrument for the small scale trial are shown in Table 1.

Table 1. Reliability and Validity Results of the TTMCT Instrument in the Small Scale Trial

Type of reliability	Value	Category
Person Reliability	0,83	Good
Item Reliability	0,75	Sufficient

Development Stage – Large Scale Trial

The large scale trial was conducted to determine the effectiveness of the developed TTMCT instrument. More specifically, the large scale trial aimed to evaluate the effectiveness of revisions made based on the analysis of the small scale trial. Large scale trials in development research are carried out with a larger number of students than in the small scale trial. The subjects of the large scale trial in this study were 75 students from grade X at SMA Negeri 1 Cawas. Data analysis was conducted using Rasch modelling through several types of analyses. The TTMCT instrument that was developed and tested in the large scale trial demonstrated good reliability, with a Person Reliability value of 0.80, an Item Reliability value of 0.90, and a Cronbach's Alpha of 0.86. Detailed reliability and validity results of the TTMCT instrument for the large scale trial are presented in Table 2.

Table 2. Reliability and Validity Results of the TTMCT Instrument in the Large Scale Trial

Type of reliability	Value	Category
Person Reliability	0.80	Good
Item Reliability	0.90	Very good

Validity analysis of the TTMCT instrument in the large scale trial was carried out by examining Item Dimensionality and Item Fit Order. Output from this analysis indicated which items actually measured what they were intended to measure in this study. Raw variance explained by measures in this study based on the large scale trial was 32.8%. Unexplained variance in the first contrast in the large scale trial had an eigenvalue of 2.1 and an observed value of 12.8%. Eigenvalues need to be less than 3 to indicate that no items are problematic, and the observed value must be less than 15% to indicate that the developed items are fit. Based on the Item Dimensionality data, the TTMCT instrument can be considered usable and free from problematic items (Lahinda & Tuerah, 2022).

Item Fit Order analysis produced data that were consistent with the Item Dimensionality analysis, namely that all developed items could be retained and were fit (Soeharto & Csapó, 2021). Further analysis involved item difficulty levels. Data analysis showed that 18 out of 25 items were in the medium to very difficult categories. Item difficulty analysis results from the large scale trial are shown in Table 3.

Table 3. Item Difficulty Analysis Results in the Large Scale Trial

No	Criteria	Range	Number of items	Item numbers
	Very difficult	>+1,37 SD	3	18, 5, 8
	Difficult	0,0 *logit* +1,37 SD	10	7, 17, 4, 6, 14, 1, 16, 3, 15, 19
	Medium	0,0 *logit* -1,37 SD	5	9, 13, 2, 25, 11
	Easy	<-1,37 SD	7	10, 12, 20, 22, 24, 21, 23

Person Measure served as one of the parameters analysed to determine students' ability levels. Students with high ability levels could answer items categorised as difficult or very difficult, whereas students with low ability levels tended to struggle and experienced difficulty in answering items in those difficulty categories (Sausan et al., 2023). Students 23LS, 33PK, and 62PD were identified as having the highest ability levels with a logit value of 4.85, while students 41PD and 67PD were categorised as having low ability levels with a logit value of −5.21.

Development Stage – Implementation Scale Trial

The implementation scale trial was conducted to determine the effectiveness of implementing the TTMCT instrument and the in depth interview activities that had been developed. Trials at the implementation scale in development research are conducted with larger numbers of students and schools than in the large scale trial. The subjects of the implementation scale trial consisted of 150 students from five schools, namely SMA Negeri 1 Cawas, SMA Muhammadiyah 1 Klaten, SMA Negeri 11 Semarang, SMA Karangturi Semarang, and SMA Negeri 3 Semarang. Improvement in the quality of the TTMCT instrument and the implementation of the in depth interviews was examined through Rasch modelling, teacher response questionnaires, and student response questionnaires. The TTMCT instrument that was developed and tested in the implementation scale trial demonstrated good reliability, with a Person Reliability value of 0.80, an Item Reliability value of 0.95, and a Cronbach's Alpha of 0.86. Detailed reliability and validity results of the TTMCT instrument in the implementation scale trial are presented in Table 4.

Table 4. Reliability and Validity Results of the TTMCT Instrument in the Implementation Scale Trial

Type of reliability	Value	Category
Person Reliability	0,80	Good
Item Reliability	0,95	Excellent

Validity analysis of the TTMCT instrument in the implementation scale trial was again carried out by examining Item Dimensionality and Item Fit Order. Output from this analysis indicated which items measured what they were intended to measure in this research. Raw variance explained by measures in this study based on the implementation scale trial was 36.7%. Unexplained variance in the first contrast in the implementation scale trial had an eigenvalue of 1.9 and an observed value of 12%. Based on the Item Dimensionality data, the TTMCT instrument can be considered usable and free from problematic items.

Item Fit Order analysis was conducted with the aim of determining the fit of each item so that information could be obtained regarding whether the items functioned normally in performing measurement. Consistent with the Item Dimensionality results, all items developed were fit and could be retained. Further analysis focused on item difficulty levels to identify the difficulty level of each item and, in a more advanced way, to observe student ability. Item difficulty analysis was conducted using Rasch modelling through the Item Measure feature in the Ministep software. This analysis yielded logit values, where high logit values indicate high item difficulty, and low logit values indicate low item difficulty. Data analysis results showed that 20 out of 25 items were in the medium to very difficult categories. Item difficulty analysis results from the implementation scale trial are shown in Table 5.

Table 5. Item Difficulty Analysis Results in the Implementation Scale Trial

No	Criteria	Range	Number of items	Item numbers
1	Very difficult	>+1,37 SD	3	18, 5, 8
2	Difficult	0,0 *logit* +1,37 SD	10	7, 17, 4, 6, 14, 1, 16, 3, 15, 19
3	Medium	0,0 *logit* -1,37 SD	7	9, 13, 2, 25, 11, 20, 22
4	Easy	<-1,37 SD	5	10, 12, 21, 24, 23

Analysis of Person Measure in the implementation stage trial showed that students 23LD, 32LD, 63PK, 112PK, 116PK, and 123PK had the highest ability levels with a logit value of 4.85, whereas students 41PK, 69PK, 132PK, and 149PK had the lowest ability levels with a logit value of −5.21. Analysis of the implementation scale trial data was continued with Differential Item Functioning (DIF) analysis. DIF analysis was conducted to determine whether there were items that favoured or disadvantaged a particular gender, because biased items are those that favour only one group with certain characteristics, thereby disadvantaging others (Christensen et al., 2022). Items with probability values less than 5% are categorised as biased items (Muliani et al., 2022). Results of the implementation scale trial analysis showed no probability values below 5%, indicating that no items were biased.

Dissemination Stage

The Dissemination stage was carried out to disseminate the product and research findings. Dissemination activities were conducted through presentations at national and international seminars.

Student Understanding Profile

Student understanding profiles on the periodic table topic, focusing on periodic properties of elements, can be identified and measured using the combination of student responses in completing the Three Tier Multiple Choice Test diagnostic instrument. Levels or profiles of conceptual understanding consist of five categories, namely Understanding the Concept (PK), Misconception (Mi), Guessing (Un), Partial Understanding (KP), and Lack of Understanding (TP). Interpretation of students' conceptual understanding can be seen in Table 6, and the detailed percentages of students' conceptual understanding profiles are presented in Table 7.

Table 6. Interpretation of Students' Conceptual Understanding

Response Combination			Classification of student response
Tier 1	Tier 2	Tier 3	
Correct	Correct	Confident	Understanding the concept
Correct	Incorrect	Confident	Negative misconception
Incorrect	Correct	Confident	Positive misconception
Incorrect	Incorrect	Confident	Full misconception
Correct	Correct	Not Confident	Guessing
Correct	Incorrect	Not Confident	Partial understanding
Incorrect	Correct	Not Confident	Partial understanding
Incorrect	Incorrect	Not Confident	Lack of understanding

Conceptual understanding analysis was conducted on 150 students in the implementation scale trial. Tables 6 and 7 present detailed results of the percentages of students' conceptual understanding profiles from the small scale and large scale trials. There are seven conceptual understanding criteria that were analysed, namely

Understanding the Concept (PK), Understanding the Concept with Low Confidence (PKKPD) or Guessing (Un), Partial Understanding of the Concept (KPK), Lack of Conceptual Understanding (TPK), Positive Misconception (M+), Negative Misconception (M−), and Full Misconception (MP). The analysis was carried out by first determining the conceptual understanding profile for each item, which was then converted into percentages.

Table 7. Percentages of Conceptual Understanding Profiles

Student criterion	Percentage (%)
Understanding the Concept (PK)	22
Understanding the Concept with Low Confidence (PKKPD)	15
Partial Understanding of the Concept (KPK)	5
Lack of Conceptual Understanding (TPK)	34
Positive Misconception (M+)	13
Negative Misconception (M−)	16
Full Misconception (MP)	20

In Depth Interview Activities

In-depth interview activities involve detailed, probing questions aimed at obtaining information as thoroughly as possible so that participants' responses can be captured in a complete and comprehensive manner. From the teachers' perspective, several factors may contribute to students' misconceptions, including low concentration during classroom instruction and limited discipline in completing practice tasks. Teachers also note that misconceptions about the periodic table can often be anticipated from students' weak understanding of prerequisite concepts required to comprehend more advanced material. From the students' perspective, misconceptions may stem from low learning motivation, particularly when instruction is dominated by lecture-based approaches, as well as decreased concentration due to external factors such as environmental, family, and economic conditions.

CONCLUSION

Development of an instrument can be considered good when its feasibility, quality, and usefulness have been tested and are aligned with the intended objectives. The Three Tier Multiple Choice Test (TTMCT) instrument and the in depth interview activities that were developed proved effective in identifying misconceptions of grade X students on the concept of the Periodic Table of Elements.

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