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Effectiveness of Multiple Representation (MR) in Removing Misconceptions Related to Acid-base Titration.

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Abstract

The study aimed to investigate misconceptions related to acid-base titration among grade eleven students and evaluate the effectiveness of Multiple Representation (MR) in addressing these misconceptions. A quasi-experimental design was used, and data were collected from 30 grade eleven students using a multiple-choice diagnostic test with open-ended reasoning questions. The diagnostic test was administered before the implementation of MR to identify areas of misconceptions. Misconceptions were identified by combining two developed instruments: the multiple-choice test and the Certainty of Response Index (CRI) scale technique. The MR intervention strategy utilized verbal, visual, and digital representations while teaching acid-base titration. A post-test was conducted to evaluate the effectiveness of MR. Descriptive analysis was employed, including measures such as mean, standard deviation, and percentiles. Inferential analysis included statistical tests such as paired sample t-tests and Cohen's d-effect size. Results from the misconception diagnostic tests revealed that 15.3% of the students had misconceptions about acid-base titration. Both descriptive analysis (MD = 11.67) and inferential analysis ($p < 0.05$, $d = 1.16$) indicated that MR was effective in removing misconceptions and enhancing academic achievement in grade eleven chemistry. Based on the findings, the researcher recommends that teachers adopt the MR strategy while teaching chemistry. The use of multiple representations, including verbal, visual, and digital elements, can help address misconceptions and improve academic achievement in the context of acid-base titration. Implementing MR in the classroom can provide students with a more comprehensive and engaging learning experience, enabling them to better understand and apply key concepts in chemistry.

Keywords*— *Multiple Representation, Quasi-experiment, Multiple-choice test, Certainty of Response Index, Chemistry, Bhutan

I. INTRODUCTION

Chemistry is widely considered one of the more challenging subjects for students to comprehend and learn. According to Senuwa (2022), chemistry is a highly intellectual science that involves numerous abstract concepts, which can often lead to misconceptions among learners. Uce and Ceyhan (2019) further emphasize that these misconceptions can result in conceptual distortions that hinder students' learning outcomes. In the field of chemical studies, acid-base titration holds particular importance as it forms the foundation for chemical analysis in several other chemistry courses (Widarti et al., 2021). However, the presence of misconceptions among learners regarding this fundamental concept poses a significant obstacle to meaningful learning. Addressing these misconceptions can be challenging using a single teaching method alone.

To address this challenge, instructional strategies play a crucial role in enhancing the effectiveness of teaching and improving students' academic achievement. According to Widarti et al. (2021), one effective teaching method for addressing misconceptions related to acid-base titration in chemistry is the Multiple Representation (MR) strategy. Similar findings supporting the efficacy of the MR strategy were presented by Widarti et al. (2018) and Sunyono et al. (2015) in their research papers. Furthermore, Widarti et al. (2017) recommended that chemistry teachers adopt the MR strategy as a 21st-century teaching tool, as it is a suitable approach for dispelling misconceptions among learners.

Currently, the study of misconceptions in chemistry is prevalent worldwide, and researchers are actively exploring various approaches to address them. In line with this, the present study aims to examine the effectiveness of the MR strategy in removing misconceptions related to acid-base titration in Bhutanese classrooms. By implementing this instructional strategy, the researchers hope to contribute to the body of knowledge on effective teaching methods in chemistry education and provide insights into how misconceptions can be effectively addressed in a specific cultural and educational context.

II. RESEARCH QUESTIONS

1. What misconceptions do grade eleven students have about acid-base titration?
2. To what extent does the MR strategy effectively eliminate misconceptions related to acid-base titration among grade eleven students?
3. How effective is the MR strategy in removing the misconception about the acid-base titration of grade eleven students?

III. REVIEW OF A RELATED LITERATURE

3.1 Acid-base titration

An acid-base titration is an experimental procedure used to determine the unknown concentration of an acid or base by precisely neutralizing it with an acid or base of known concentration. An equivalence point, of a titration, is the point at which chemically equivalent quantities of reactants have been mixed. A solution of accurately known concentration is known as a standard solution (titrant) and is prepared by dissolving an accurately weighted amount in a definite volume (Garg, 2009). The solution whose concentration has to be determined is known as the analyte (titrand). According to Ahumada and Meija (2019) the purpose of titration is to establish the amount of a substance present in the solution by chemically reacting that substance with a standard solution of known concentration

The endpoint of a titration is the point at which the indicator used gives a usual color change at the end of the titration. The indicator is a substance, the presence of which during the titration makes the endpoint visible either by appearance or disappearance of color or colored precipitate. The commonly used indicators are phenolphthalein, methyl orange, methyl red, blue chlorophenol, bromothymol blue, and red cresol. Table 1 displays the types of acid-base titration with examples.

Table 1: Types of Acid-Base Titration

Sl. No.	Types	Example
1	Strong acid-strong base	Hydrochloric acid and sodium hydroxide
2	Weak acid-strong base	Ethanoic acid and sodium hydroxide
3	Strong acid-weak base	Hydrochloric acid and ammonia
4	Weak acid-weak base	Ethanoic and ammonia

3.2 Misconception on Acid-base Titration

Misconceptions regarding acid-base titration are prevalent among students, particularly concerning the equivalence point, the role of indicators, and the nature of acids and bases in titration (Supatmi et al., 2019). A review of common misconceptions in science by Soeharto et al. (2019) similarly revealed that students often encounter difficulties in comprehending acid-base chemistry concepts. The misconceptions can be attributed to a limited understanding of acid-base concepts and a lack of practical experience with titration in the laboratory, including exposure to various indicators and types of titrations (Supatmi et al., 2019). Widarti et al. (2017) also reported a common misconception among learners regarding the equivalence point in acid-base titrations. Many students incorrectly believe that the endpoint of a titration always occurs at pH 7, whereas in reality, it can take place at various pH values and is not restricted to pH 7.

Misconceptions can hinder effective learning by creating barriers and resistance to change, thereby impeding further exploration and understanding. Students often interpret the world based on their sensory experiences, and these interpretations may not align with accepted scientific theories. Consequently, students may find it challenging to let go of their misconceptions, particularly if they have held them for a significant period (Canpolat, 2006; Pabuçcu & Geban, 2006). Such misconceptions can undermine the learning process and hinder the acquisition of accurate knowledge.

Diagnostic tests, such as the two-tier and three-tier tests were employed by previous researchers to identify misconceptions and assess students' understanding. The study conducted by Supatmi et al. (2019) utilized a two-tier multiple-choice diagnostic test to identify and analyze students' misconceptions. Likewise, a study conducted by Jatmiko and Yonata (2021) used a three-tier test to diagnose misconceptions about acid-base theory among prospective teacher students. The diagnostic tests helped researchers to identify the misconceptions and would help improve students' understanding and mastery of acid-base titration concepts.

3.3 Effectiveness of MR Strategy

According to Supatmi et al. (2019), to effectively learn about acid-base titrations, students should first develop a solid understanding of acid-base reactions before engaging in titration experiments. This foundational knowledge is crucial for comprehending the underlying principles and processes involved in acid-base titrations. Therefore, it is essential to employ an active teaching strategy to eliminate misconceptions and promote accurate understanding. The study conducted by Widarti et al. (2021) recommended Multiple Representation (MR) as an effective strategy for removing misconceptions while teaching volumetric analysis. Likewise, Kurnaz and Arslan (2013) also reported in their study that the use of MR strategy enhances the students learning. Similarly, Abdurrahman et al., (2018) also reported that the MR helps students solve problems and enhance critical thinking. Moreover, Hand and Choi (2010) reported that MR positively impacted the ability to construct students' arguments in laboratory classes.

Verbal, visual, and digital representations were utilized throughout the intervention. Visual representations encompass images, diagrams, charts, graphs, and the experimental apparatus necessary for the titration process. Verbal representations involve the use of spoken or written language, such as lectures, discussions, explanations, textbooks, handouts, and written assignments, to convey information. Additionally, digital representations, including simulations and videos, were employed to present the concepts of acid-base titration to the students.

Verbal representation is an important teaching strategy that can help remove misconceptions in students. Hansen and Richland (2020) highlight the importance of verbal representation in helping students reason about visual representations in science and establish connections across different representational systems. Multiple representations, including verbal representation, can effectively reduce misconceptions among students by offering clear explanations and illustrative examples (Alamian et al., 2020). However, there are concerns that multiple representations may overwhelm learners' cognitive resources, hindering their ability to fully process and reason based on the provided information (Hansen & Richland, 2020).

Visual representation is another important teaching strategy that can help remove misconceptions in students. According to Hansen and Richland (2020) visual representations play a crucial role in science education by supporting cognitive understanding and utilization of visual representations has been proven effective in facilitating cognitive comprehension in science. Likewise, in a study on ninth-grade students, the use of visual representations and manipulatives was found to be effective in reducing algebraic misconceptions (Alamian et al., 2020).

Digital representations, such as simulations and videos, are modern pedagogical approaches used to address scientific misconceptions. Research by Beal et al. (2017) and İsmailoğlu et al. (2020) found simulations and videos to be highly effective in acquiring skills and knowledge. Plass et al. (2012) asserted that well-designed computer simulations are beneficial for enhancing student understanding of complex chemistry concepts. Nursing students also benefit from simulations, as they improve knowledge, performance, self-satisfaction, and confidence (D'souza et al., 2017). Similarly, the use of videos in courses has been shown to significantly enhance student learning and reinforce conceptual understanding (Ramachandran et al., 2019).

IV. METHODOLOGY

The research design used in this study was a quasi-experiment utilizing nonrandomized assignments. Creswell and Creswell (2018) define a quasi-experiment as an empirical interventional study that does not utilize randomization to establish the causal effects of an intervention on the target population. Data for this study was collected with the help of a two-tiered test from a section of (N=30) purposefully selected grade eleven science students. The research instrument used was a multiple-choice diagnostic test with open reason. The instrument included ten acid-base titration questions. The diagnostic test was conducted before learning (pre-test) and after the implementation of MR (post-test).

After conducting the pre-test to confirm the misconceptions about acid-base titration, MR consisting of verbal, visual, and digital representations was used as an intervention strategy while teaching acid-base titration Misconception identification was done by combining two developed instruments, multiple-choice tests, and the Certainty of Response Index (CRI) scale technique modified by Hasan et al. (1999). The analysis of students' understanding is shown as a decision matrix for the two-tier test in Table 2.

Table 2: Decision matrix for the two-tier test

#	Answer	CRI	Interpretation
1	Correct	Low (< 2.5)	Lack of knowledge (lucky guess)
2	Wrong	Low (< 2.5)	Lack of knowledge
3	Correct	High (> 2.5)	Knowledge of correct concepts
4	Wrong	High (> 2.5)	Misconceptions

Note. Adapted from Hasan et al. (1999).

V. DATA ANALYSIS AND RESULTS

This study was conducted to answer two research questions. One of the objectives of the study was to answer the question "*What misconceptions do grade eleven students have about the concept of acid-base titration?*" After conducting the pre-test, it was found that 15.3% of the students had misconceptions about the volumetric analysis.

Table 3: Pre-test and Post-test scores in different decision matrices matrixes

	No Concept	Misconception	Lucky Guess	Certain
Pre-test	12 %	15.3 %	30.3 %	42.3 %
Post-test	0.3 %	5.3 %	1.7 %	92.7 %

Table 3 shows a decrease in students' misconceptions from 15.3% in the pre-test to 5.3% in the post-test. This outcome indicates that the implementation of the MR strategy effectively reduces students' misconceptions about acid-base titration.

Table 4: Percentage of misconceptions in each question in the pre-test

Question No.	Concepts	Misconception	
		Pre	Post
1	Methyl orange can also be used as an indicator during strong acid-base titration	10 %	3.3%
3	The equivalence point and endpoint of the titration are the same	16.7%	10 %
4	The pH of the endpoint in the acid-base titration is neutral	36.7%	20 %
6	The endpoint of the acid-base titration is slightly basic.	30 %	0
7	The burette used for the titration should be rinsed with distilled water followed by the titrant.	10 %	0
9	Burette reading from the pictorial diagram	13.3%	0
10	Rinsing is a process of washing a burette or pipette with distilled water followed by an analyte to be filled in it.	36.7%	20 %

Similarly, Table 4 illustrates students' misconceptions regarding different concepts related to acid-base titration. The pre-tests revealed that the highest percentage of misconceptions among students was associated with question numbers 4 and 10, both with a rate of 36.7% for each question. In the post-test, the students demonstrated complete elimination of misconceptions for question numbers 6, 7, and 9, while there was a reduction in misconceptions for the remaining questions. Overall, these findings indicate significant progress in addressing student misconceptions between the pre-test and post-test assessments.

Another objective of the study was to answer the research question "***To what extent does MR effectively eliminate misconceptions related to acid-base titration among grade eleven students?***" Figure 3 answers the research question based on the student's achievement score in the pre-test and post-test that fall in different decision matrices.

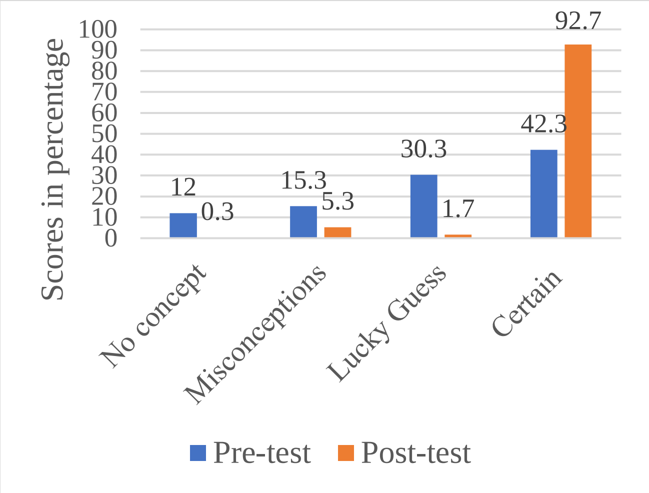

Fig.3 Students that fall in different decision matrices in pre-test and post-test in percentage

Figure 3 shows that 12% of the students lack a basic concept of acid-base titration, while 15.3% of the students hold misconceptions about this topic. Additionally, approximately 30.3% of the students arrived at correct answers through lucky guesses, while 43.3% of the students were confident in their responses. Following the implementation of the MR intervention, a minimal percentage of students failed to grasp the concepts, and there were also fewer students with misconceptions or relying on lucky guesses. The majority of students (92.7%) were able to answer the questions confidently after the intervention.

The final objective of the study was to answer the research question ***"How effective is MR in teaching the acid-base titration concepts of grade eleven science students?"*** To answer the research question, a descriptive analysis was conducted using the test scores of the (*N*=30) students. Furthermore, an inferential analysis was performed to determine the significant mean difference between the post-test and pre-test scores. Statistical terms such as mean, standard deviation, t-value, df-value, and p-value were utilized in the data analysis process.

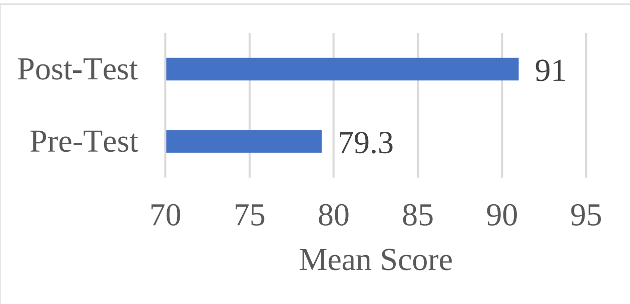

Fig.2: Students' pre-test and post-test mean scores

Figure 2 and Table 5 shows the mean pre-test score of the (*N*=30) grade eleven students was 79.3 (*SD*=10.48), and the mean post-test score was 91.0 (*SD*=9.59). While comparing the mean of the two tests there was an improvement in test scores as shown in Figure 2, and Table 5 indicating MR is effective in removing the misconceptions related to acid-base titration.

Table 5: Paired Samples Statistics

	N	Mean	Std. Deviation
Pre-Test	30	79.3	10.48
Post-Test	30	91.0	9.59

Further, an inferential statistical test was conducted with a 95% confidence level to determine the statistical significance of these findings and draw more robust conclusions. A paired-sample t-test was run with 95% confidence and revealed that there was a significant mean difference between the tests, t (29) = 5.347, p < 0.05 as shown in Table 5. The calculated Cohen's d was 1.16 which indicates the effect size was large.

Table 5: Paired Sample t-test for pre-test and post-test

	Paired Differences					
	Mean	**SD**	**t**	**df**	**Sig. (2-tailed)**	**Cohen's d**
Post-Test – Post-Test	11.67	15.33	4.17	29	.000	1.16

*Significant <0.05

VI. DISCUSSION

The study found that 15.3% of the students held misconceptions related to acid-base titration. This finding aligns with previous studies conducted by Pinarbasi (2007), Rahayu et al. (2011), Siswaningsih et al. (2020), and Widarti et al. (2021) that also reported misconceptions among learners regarding acid-base titration. Additionally, this study revealed that approximately 36.7% of students had misconceptions regarding the pH of the endpoint in acid-base titration, and 16.7% of students were unable to differentiate between the equivalence point and endpoint of the titration. These findings are consistent with the results reported by Widarti et al. (2017) and Supatmi et al. (2019), where some learners mistakenly assumed that the endpoint and equivalence point of the titration were the same. These findings reinforce the importance of providing clear and accurate explanations of these concepts during acid-base titration instruction. By identifying these misconceptions, educators can tailor their teaching approaches to effectively address the specific areas where students may struggle and promote a more accurate understanding of acid-base titration.

The study found that the implementation of the MR strategy in teaching chemistry was seen to be effective in eliminating misconceptions and improving academic achievement. Evidence of this effectiveness can be seen in the higher scores achieved by students on the post-test (91%) compared to the pre-test (72.7%). Similarly, research conducted by Widarti et al. (2021) also concluded that the MR strategy effectively removed misconceptions during the teaching of volumetric analysis. Additionally, a study conducted by Kurnaz and Arslan (2013) affirmed that the utilization of the MR strategy enhanced student learning. The findings indicate that the MR strategy is an effective approach for mitigating misconceptions and promoting academic achievement in the context of chemistry education.

The study's findings also revealed that after the implementation of the MR strategy, only a minimal percentage of students struggled to grasp the concepts. Additionally, there were fewer students with misconceptions, as well as those who relied on lucky guesses to provide correct answers. The majority of students (92.7%) demonstrated confidence in their ability to answer the questions after the intervention. These findings align with similar research conducted by scholars such as Hand and Choi (2010), Abdurrahman et al. (2018), and Widarti et al. (2021) in their respective studies. Collectively, these studies provide further evidence supporting the effectiveness of the MR strategy in improving students' conceptual understanding, reducing misconceptions, and promoting confidence in their learning outcomes.

VII. CONCLUSION

The study concluded that the MR strategy was highly effective in removing misconceptions in chemistry and facilitating effective content delivery, leading to improved academic performance among students. Based on these findings, the researcher strongly recommends that chemistry teachers adopt the MR strategy as a teaching approach in their classrooms. By incorporating the MR strategy, teachers can proactively address and correct misconceptions, ultimately enhancing students' understanding and academic achievement in chemistry.

Furthermore, the researcher encourages future researchers to explore the effectiveness of the MR strategy in removing misconceptions across various subjects. By investigating its applicability beyond chemistry, researchers can contribute to the broader understanding of how the MR strategy can be utilized as an effective teaching strategy in different educational contexts. Such research endeavors would provide valuable insights into the potential benefits of the MR strategy in enhancing students' conceptual understanding and academic performance in a range of subject areas.

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