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Use of Multiple Representations in Online General Chemistry Class: Promoting Chemical Understanding during the Covid-19 Pandemic

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ABSTRACT

Teaching and learning in chemistry have been shifted to online classes due to the pandemic. With this, researchers investigated the use of multiple representations embedded to determine its effectiveness in online learning setup. A pretest-posttest with control quasi-experimental design was employed to two groups of Grade 11 STEM students taking up a general chemistry course in a private secondary institution in Cebu City, Philippines. The control group (n=30) was exposed to typical online class while the experimental group (n=30) was exposed to the multiple representations. Study findings revealed that there have been significant mean gains for both groups, indicating the important role of online learning in chemistry. The experimental group (MD=3.03, t=2.495, p=.015) had significantly higher mean gains than the control group, signifying the more effective nature of multiple representations in chemistry teaching. Moreover, the students had highly favorable attitudes towards multiple representations and had average extents of understanding in the macroscopic, microscopic, and symbolic levels. Therefore, the use of multiple representations promotes students' chemical understanding during the Covid-19 pandemic. The researchers recommend the use of these representations in chemistry teaching, where teachers start at the macroscopic level before they proceed to the more abstract levels.

Keywords: *attitudes, COVID-19 pandemic, general chemistry, multiple representations, online learning*

INTRODUCTION

The Covid-19 pandemic has brought changes in the teaching and learning delivery of Chemistry. Classes are modified to suit to the current quarantine protocols, shifting from physical face-to-face classes to virtual engagements. This shift becomes the feasible solution to continue learning amidst the pandemic, leading teachers to apply teaching strategies that suit to the nature of online learning. Chemistry teachers across the globe formulate and find strategies that best work in their respective contexts, from the use of pre-recorded lecture videos (Pilkington & Hanif, 2021), immersive online platforms (Guo et al., 2020), and interactive synchronous lectures (Krishnamurthy, 2021) to gamified environments (da Silva et al., 2020) and home-based laboratory experiments (Sanchez et al., 2021). Another strategy of focus is the use of multiple representations in online learning in Chemistry.

Multiple representations incorporate three modes of representation based on the Chemistry Triangle (Johnstone, 1982). These modes of representation offer understanding of chemical concepts in various perspectives (Luviani et al., 2021). The macroscopic mode is used when the senses are used to observe matter and its changes during practical work (Lewthwaite, 2014). The submicroscopic mode deals with the visualization of matter and its behavior at the level of particles, may these particles be atoms, molecules, and even ions (Santos & Arroio, 2016; Gumonan & Bug-os, 2021). The third mode denotes the symbolic nature of chemistry, wherein abstract representations such as chemical symbols, expressions, and equations are used (Liu & Taber, 2016). The interplay of these chemical modes helps students make meaning of the different phenomena, leading to deeper understanding of chemistry lessons (Jaber & Boujaoude, 2012; Sanchez, 2018; Lorduy & Naranjo, 2020).

The use of multiple representations has been investigated in physical face-to-face settings in the pre-pandemic world. Multiple representations are employed to promote understanding of chemical concepts such as ideal gas (Madden et al., 2011), structure of matter (Yakmaci-Guzel & Adadan, 2013), particle theory of matter (Adadan, 2013), and physical and chemical changes (Derman & Ebenezer, 2020). Learning materials are also developed to increase the ability to connect to chemical phenomena in high school chemistry (Farida et al., 2018; Rivera & Sanchez, 2020) and materials chemistry (Helsy et al., 2017). Structured instructional models or strategies incorporating the macroscopic, microscopic, and symbolic modes are formulated or applied to facilitate understanding on chemical reactions (Chandrasegaran et al., 2011; Jaber & Boujaoude, 2012), atomic structure (Sunyono et al., 2015), redox reactions (Widarti et al., 2016), gases (Sanchez, 2017), and acids and bases (Pikoli, 2020). Furthermore, the multiple representation levels are also investigated to explore how students and teachers view chemical phenomena like redox reactions (Li & Arshad, 2014) and kinetic theory of gases (Sanchez, 2018; 2021).

However, the use of multiple representations during the shift to online learning delivery during the pandemic proved to be a challenge among teachers. There is a difficulty in presenting the chemistry content and communicating the different levels of macro, micro, and symbolic content to the students online and remotely (Lansangan, 2020). Additionally, only a handful of researches were conducted to determine the effects of using multiple representations in online or blended learning modality, such as conducted by Munzil & Marfu'ah (2021) and Mulyani et al. (2022). With this, the researchers adapted the macro-micro-symbolic approach in teaching chemistry to promote chemical understanding during the pandemic, as its effectiveness has not been documented in the context of the Philippines.

The present study investigated the effectiveness of multiple representations in promoting the chemical understanding of high school students as they study online during the pandemic through the difference of mean gains from pretest and posttest performances. The results of the study are significant because these results provide insights as to the effects of providing multiple perspectives of the chemical concepts especially during the online learning delivery. Also, the effectiveness of the multiple representational strategy may suggest ways how to enhance the online learning experience of students in chemistry, hence, the conduct of the study.

Statement of the Problem. This study investigated the effectiveness of multiple representations on an online General Chemistry class of Grade 11 STEM students in a private university in Cebu City, Philippines. Specifically, it described and compared the performances between the control group (exposed to the typical online class) and experimental group (exposed to the multiple representations during online class); and described their level of attitudes and extent of understanding along the three modes of representation, namely, macroscopic, microscopic, and symbolic levels.

METHODS

Research Design, Environment, and Respondents. The study employed the pretest-posttest with control quasi-experimental design to determine the effect of multiple representations on understanding chemistry concepts, particularly on the mole concept. The mole concept is considered to be one of the least mastered competencies in chemistry that includes topics such as chemical reactions, stoichiometry, and limiting reactants (Taborada & Sanchez, 2020). The quasi-experiment was carried out in the Senior High School department of a private university in Cebu City, Philippines. The Grade 11 STEM students from this basic education department participated in the study. The students were grouped into control and experimental groups with 30 intact students each. The control group was exposed to the typical online class while the experimental group was exposed to the multiple representations. Both groups had comparable entry performances at 95% confidence level (t=0.380; p=.705).

Research Instruments. The study employed two research tools. The first tool was a validated pretest/posttest consisting of 30-items about chemical reactions, stoichiometry, and limiting reactants as presented in the table of specification below (Table 1). In this tool, there were 8 items on the macroscopic mode, 11 items on microscopic mode, and 11 items on symbolic mode, totaling 30 items in the pretest/posttest. This tool was validated by three experts in Chemistry teaching and pilot-tested to a group of 30 Grade 12 students in the same private university, obtaining an acceptable reliability (α=0.792). The other instrument was modified from the Attitude Towards Use of Particle Diagrams (Lausin & Kijai, 2020), incorporating 10-Likert scale items to measure the extent of attitudes towards multiple representations after the implementation of the pedagogy to the experimental group. It was also pilot-tested to the same group of Grade 12 students, resulting to a good reliability (α=0.820).

Table 1. Table of specifications of the validated pretest/posttest

Topics	Level of the Cognitive Domain[1]						Total items
	R	U	Ap	An	E	C	
Chemical Reactions	6,8	3,13	2,4	1,5	-	-	8
Stoichiometry	10	24	22	9,11,15-18,21,23	-	-	11
Limiting Reactants	20,30	7,19	28	12,25-27,19	14	-	11
Total items	5	5	4	15	1	0	30

[1] Levels based on revised Bloom's taxonomy: R=remembering, U=understanding, Ap=applying, An=analyzing, E=evaluating, C=creating

Data Gathering Procedures. The researchers underwent four stages during the data gathering phase of the study.

Research Permissions. Before the study commenced, pertinent permissions were obtained to ensure the proper conduct of the quasi-experiment. The researchers submitted the manuscript for ethics review by the university ethics committee. After getting the certification, permission was asked from the school principal of the Senior High School department of the private university. Once this permission was secured, assent and informed consents were asked from parents and students for their approval to voluntarily participate in the study.

Pretesting. When all permissions were secured, the researchers proceeded to the pretesting stage of the study. The research tools (pretest and attitude questionnaire) were administered to the students a week before the implementation of the research pedagogies. These tools were administered online through the use of Google Forms. The forms were set to be answered once using the school email of the students.

Quasi-experimentation. The quasi-experimentation lasted for eight weeks. There were a total of six lessons, with two lessons each on chemical reactions, stoichiometry, and limiting reactants. The control group was exposed to the typical science online class. In this typical science class, students were given springboard activities that led to the presentation of the topic. Afterwards, synchronous class through classroom discussion and problem solving followed. The class ended with questions and clarifications, and eventually generalization of the topic.

The experimental group was exposed to multiple representations, adopted with modification from Sanchez (2017). In this instruction, three stations were planned, each corresponding to a chemical mode. The first station lets the students view a multimedia experimentation, where they had hands-on observations (*macroscopic*). In the second station, they viewed the chemical phenomenon using particulate diagrams (*microscopic*). In the last station, they solved a problem based on their observations and particulate diagrams (*symbolic*). After these station activities, the teacher facilitated the questions and clarifications, and the class ended through a generalization.

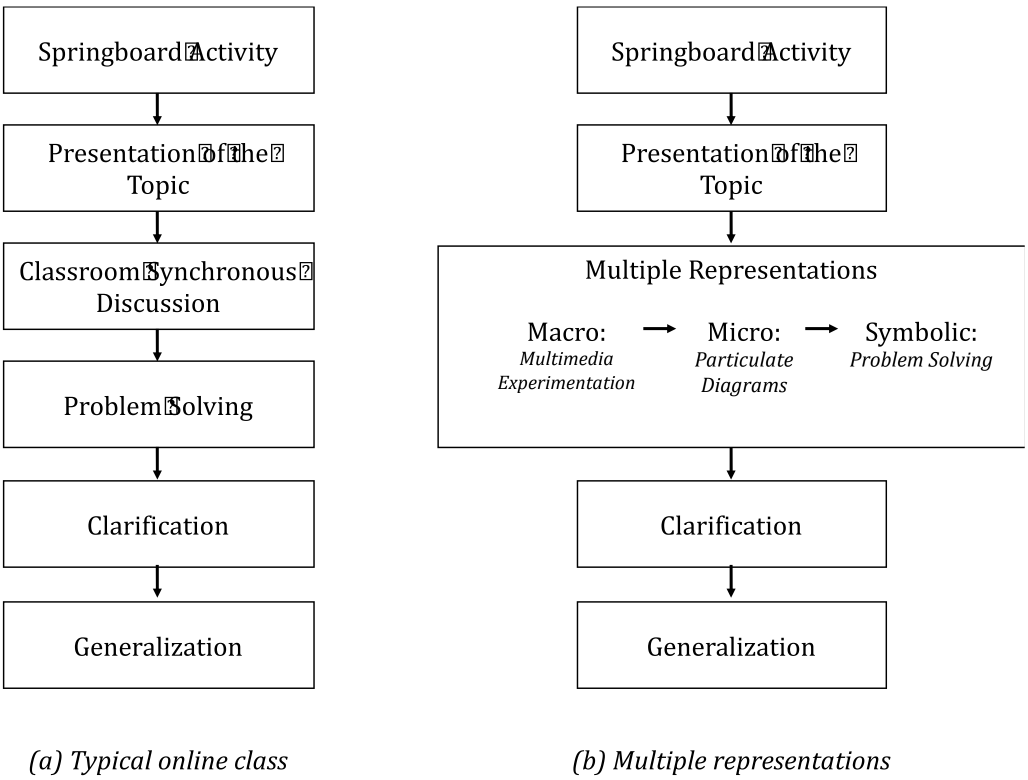

Figure 1. Implementation plan for (a) control group and (b) experimental group

Table 2. Topics discussed and the modes of representation

Topics	Macro	Micro	Symbolic
Chemical reactions	Lab experiments	Atomic/ molecular diagrams	Complete, balanced chemical equations
Stoichiometry	Everyday activities Lab experiments	Interactive particulate diagrams	Complete, balanced, chemical equations Word problems
Limiting reactants	Everyday activities Lab experiments Industrial applications	Interactive particulate diagrams Animations	Complete, balanced chemical equations Word problems Percent yield

Posttesting. After the eight-week pedagogical implementation, the posttest tools were administered online using the same Google Forms platform. All data were collected and organized in Microsoft Excel, encrypted with a password to protect the data.

Data Analysis. The data collected from the pretest and posttest were analyzed using descriptive and inferential statistical tools. The students' performances, attitudes, and extent of understanding along the three modes were described using means and standard deviations. The data were subjected to Shapiro-Wilk test, resulting to p-values greater than .05 that indicated normal data distribution. Due to this normal distribution, the comparative analyses were done through parametric tests (*t*-test for dependent samples and independent samples). Effect size was described as Cohen's d, appropriate for two groups with similar sample size and standard deviations, with bigger Cohen's d values denote bigger mean gains or differences in the mean gains between two groups (Enzmann, 2015). All inferential tests were conducted at 95% confidence levels and all p-values less than .05 were considered significant.

Ethical Considerations. The study was submitted to the university ethics committee for ethics review. Pertinent permissions from the school principal, parents, and students were secured. The said stakeholders were informed of the study's nature, goals, benefits, risks, and compensation, their voluntary participation and withdrawal at any point of the study. All data gathered from the tests and questionnaires were kept confidential and all names remained anonymous all throughout the conduct of this study.

RESULTS AND DISCUSSION

Students' Performances in General Chemistry. The pretest and posttest performances of the students in General Chemistry are presented in Table 3.

Table 3. Pretest and posttest performance of students in General Chemistry

Group	Performance	Mean	SD	*t*-value[1]	*p*-value	Description
Control	Entry	13.90	4.03	-11.692*	.000	Below Average
	Exit	18.03	4.76	-5.140*	.000	Below Average
Experimental	Entry	13.50	4.12	-11.974*	.000	Below Average
	Exit	20.67	5.10	-1.968	.059	Average

[1] One sample t-test, where hypothetical mean is set at 75% (HM=22.5)
* Significant at α =.05

Based on Table 3, both the control group (μ=13.90, SD=4.03) and experimental group (μ=13.50, SD=4.12) had below average pretest performances. After the implementation of the typical online class, the control group still had below average performance (μ=18.03, SD=4.76). In contrast, the experimental group had average performance (μ=20.67, SD=5.10) after their exposure to the multiple representations in their online general chemistry class. The increased score in the exit performances suggests that the students gained knowledge and skills through the online learning delivery present in both groups. Online learning offered opportunities for students to continue learning, acquire knowledge and skills, and achieve better in Chemistry even amidst the Covid-19 pandemic (Kalman et al., 2020; Sintema, 2020; AlMahdawi et al., 2021).

Comparison between Entry and Exit Performances in General Chemistry. The pretest and posttest performances were compared for the control and experimental groups. The statistical results of the comparison are shown in Table 4.

Table 4. Comparison between pretest and posttest performances in Gen. Chemistry

Group	Mean Gain	SD	*t*-value	*p*-value	Cohen's d
Control	4.13	4.10	5.522*	.000	1.01 (large)
Experimental	7.17	5.25	7.482*	.000	1.37 (large)

* Significant at α =.05

According to Table 4, the control group (t=5.533, p=.000) had a significant gain from their pretest to posttest performance with a large effect size (d=1.01). This means that the students in this group had significantly increased their performance after the conduct of typical online class. This could be attributed to the flexibility of online classes that paved way for students to enhance their performances. Virtual classes have positive effect to chemistry classes even before pandemic (Gulacar et a., 2013; Ratniyom et al., 2016; Faulconer et al., 2018) and much more during pandemic times (Kalman et al., 2020; Sintema, 2020; AlMahdawi et al., 2021).

The experimental group (t=7.482, p=.000) also had significant mean gain from the pretest to posttest performance with a large effect size (d=1.37). This indicates that the students in this group had significantly enhanced their performance after the implementation of the multiple representations embedded in their online class. This could be due to the representational nature of the pedagogy, incorporating different perspectives of the chemistry phenomenon. Multiple representations are observed to have positive and significant gains across literature (Madden et al., 2011; Yakmaci-Guzel & Addan, 2013; Adadan, 2013; Derman & Ebenezer, 2020), making these representations valuable for the flexible learning modality that students are in during the pandemic (Munzil & Marfu'ah, 2021; Mulyani et al., 2022).

Comparison between the Mean Gains of the Control and Experimental Groups. The mean gains of the control and experimental groups were compared and the results are reflected in Table 5.

Table 5. Comparison between mean gains of the control and experimental groups

Group	Difference in Mean Gains (MD)	SD	*t*-value	*p*-value	Cohen's d
Control	3.03	4.44	2.495*	.015	0.64 (large)
Experimental					

* Significant at α =.05

As reflected in Table 5, there has been an observed significant difference in the mean gains between the control and experimental groups (t=2.495, p=.015) still with large effect size (d=0.64). This signifies that the experimental group gained more learning than the control group, indicating the more effective nature of multiple representations over the typical online class. Three reasons are seen to have attributed to the effective nature of multiple representations in teaching online chemistry course. Firstly, the different perspectives that the strategy has brought into the online class, providing students with various explanations about chemical reactions, stoichiometry, and limiting reactant. Different modes of representation promote understanding of the chemical phenomenon at hand (Sanchez, 2017; Luviani et al., 2021) and interplay of these modes of representation create a meaningful learning experience among the students (Jaber & Boujaoude, 2012; Sanchez, 2018; Lorduy & Naranjo, 2020).

Moreover, the present experimental pedagogy consists of several modes that start in the macroscopic level. This level offers opportunities for students to observe experiments even in online settings. Through the use of recorded and actual synchronous demonstrations, the students were able to describe and observe the phenomenon in the macroscopic scale. When they observe what happens in the bigger scale, they can gain insights on the possible behavior of matter in the particulate scale as well as chemical or mathematical relationships in the symbolic level. Effective chemical understanding is achieved when instruction begins in the macroscopic level and introduce symbols only after the microscopic level (Sanchez, 2021). As students are provided with opportunities to experience the phenomenon at the macroscopic level, they are offered more meaningful connection to the microscopic level (Schmidt, 2021). Converting visualizations from macro to micro then to symbolic levels contribute to students' understanding in chemistry, including stoichiometry (Sujak & Daniel, 2017).

Furthermore, the flexible nature of online class where the multiple representations are embedded also offered opportunities to continue chemistry learning amidst the pandemic. This flexibility enabled the students to acquire knowledge and skills and perform better than before. Online classes become the platform for acquiring knowledge and skills and achieving better (Kalman et al., 2020; Sintema, 2020; AlMahdawi et al., 2021). Students' engagement and self-motivation can be enhanced in flexible learning in chemistry (Lo et al., 2021).

Students' Attitudes towards the Multiple Representations. The students exposed to the multiple representations embedded in their general chemistry class were surveyed concerning their attitudes towards the said representations. Their level of attitudes is presented in Table 6.

Table 6. Level of attitudes towards the multiple representations

The multiple representations helped in…	Mean	SD	Description[1]
1. visualizing the particles that make up compounds and elements.	4.53	0.68	Highly favorable
2. determining the amounts of substances needed or produced in a chemical reaction.	4.53	0.63	Highly favorable
3. understanding what happened to the reactant particles during chemical reactions.	4.50	0.63	Highly favorable
4. determining each kind of atom that takes part in a chemical reaction.	4.40	0.72	Highly favorable
5. understanding the difference between theoretical and actual yield.	4.40	0.72	Highly favorable
6. understanding what the coefficients in balanced chemical equations represent.	4.37	0.81	Highly favorable
7. relating coefficients to mole ratio.	4.33	0.76	Highly favorable
8. Identifying which reactant determines the theoretical yield.	4.30	0.79	Highly favorable
9. identifying the reactant that is not all used up.	4.27	0.78	Highly favorable
10. identifying the reactant that is all used up first.	4.17	0.70	Favorable
Overall Attitude Level	*4.38*	*0.53*	*Highly favorable*

[1] Legend: 1.00-1.80 (Unfavorable), 1.81-2.60 (Slightly favorable), 2.61-3.40 (Moderately favorable), 3.41-4.20 (Favorable), 4.21-5.00 (Highly favorable)

Based on Table 6, the students had highly favorable attitudes towards multiple representations, in terms of the ability of the strategy to visualize particles, understand chemical reactions, stoichiometry, and limiting reagents, and derive significant information from the chemical equations. Additionally, they had favorable attitudes towards the ability of the strategy to identify the used-up reactant. Overall, they had highly favorable attitudes towards the strategy (μ=4.38, SD=0.53), as they are given opportunities to understand better general chemistry concepts. Multiple representations in chemistry have positive impact to students' chemical understanding and leads to positive attitudes towards these representations (Lausin & Kijai, 2020). The availability, usability and relevance of representations as embedded in instructional methods aids pave way for positive attitude towards chemistry to be attained (Habiddin et al., 2020; Musengimana et al., 2021).

Students' Understanding on Macro, Micro, and Symbolic Content. The researchers also analyzed the understanding of the students along the macroscopic, microscopic, and symbolic modes. The descriptions on these three modes are shown in Table 7.

Table 7. Extent of students' understanding on macro, micro, and symbolic content

Mode	Entry		Exit		MD	t-value	p-value
	Mean (SD)	QD[1]	Mean (SD)	QD[1]			
Macroscopic	4.13	BA	5.57	A	1.43	5.582*	.000
Microscopic	4.87	BA	7.60	A	2.72	5.040*	.000
Symbolic	4.50	BA	7.50	A	3.00	7.821*	.000

* Significant at α =.05

[1] Qualitative Description based on one-sample t-test using hypothetical mean at 75% of the total score (macro HM=6; micro HM=8.25; symbolic HM=8.25):

p>.05: Average (A)
p<.05, mean<HM: Below Average (BA)
p<.05, mean>HM: Above Average (AA)

As shown in Table 7, students exposed to the multiple representations had below average entry performances across the three levels and enhanced these performances into average-level exit performances. Paired comparison between these two performances for all the modes of representation (macro: t=5.582, p=.000; micro= t=5.040, p=.000; symbolic= t=7.821, p=.000) yielded significant improvements before and after the implementation of the multiple representations. This finding suggests that the use of these representations in online class are effective in improving the performances of the students. The representations provide mechanisms to support learning and provide deeper understanding of the topic at hand (Jaber & Boujaoude, 2012; Lorduy & Naranjo, 2020; Sanchez, 2021).

In the macroscopic level, the students were provided recorded and actual synchronous demonstrations. Through these demonstrations, students were able to derive valuable information which they can use when dealing with the more abstract representations (Sanchez, 2021; Schmidt, 2021). Demonstration experiments can result to significant gains in chemistry (Trivic & Milanovic, 2018). In the microscopic level, the students were given opportunities to visualize the chemical phenomenon in the particulate level. Iconic representations such as illustrations, pictures, animations, and even simulations become advantageous in exploring the chemical phenomenon. Competence in the microscopic level is inconsistent in the read literature; some studies report good results (Winarti et al., 2018; Sanchez, 2021) while others mention low scores (Serobatse et al., 2014; Güven & Uyulgan, 2021). But during the pandemic, iconic representations were designed and embedded in online platforms, which are feasible to be utilized and can result to significant gains in chemistry (Patron et al., 2021; Mahanan et al., 2021; Munzil & Perwira, 2021). Furthermore, in the symbolic level, the students were able to interpret the chemical equations appropriately and solve stoichiometric problems correctly. Chemical equations and problems are dealt with correctly because the students have been exposed to the demonstrations and iconic representations. These macroscopic and microscopic representations helped them gain understanding when the phenomenon was translated to symbols. The macro and micro modes are essential in understanding the abstract and more symbolic nature of chemistry (Sanchez, 2021; Schmidt, 2021).

CONCLUSIONS

The use of multiple representations in online classes is effective (MD=3.03, t=2.495, p=.015) in teaching general chemistry course in the secondary level, thereby promoting chemical understanding during the Covid-19 pandemic. This effectiveness can be seen in the significant improvement in the students' performance, the favorable attitudes towards the representational nature of chemistry, and the high extent of chemical understanding in the three modes of representation. The study recommends that multiple representations be used in online or blended learning during any pandemic and face-to-face classes once physical classes resume post-pandemic. Teachers may employ activities in chemistry, following the macro, micro, and symbolic progression, to ensure learning in the new normal. Future researchers may use the present study findings as baseline data for further investigations regarding the use of multiple representations in virtual settings. Other complex and difficult concepts in chemistry may be investigated to establish the effectiveness and importance of multiple representations in the said subject.

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