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Evaluating the effect of custom developed dynamic simulations on students conceptual understanding of chemical equilibrium: A mixed methods analysis

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Abstract

The purpose of this study is to evaluate the role of custom developed dynamic simulation towards development of student's concrete conceptual understanding of chemical equilibrium. An explanatory sequential mixed methods design was used in the study. Results from a one-factor ANCOVA showed posttest scores were significantly higher for the experimental group (Mpost. = 7.27 SDpost = 1.387) relative to the control group (Mpost. = 2.67, SDpost = 1.371) after adjusting for pretest scores, F (1,24) = 71.82, MSE = 1.497, p = 0.03, $\eta_p{}^2$ = 0.75, d = 3.33. According to the procedure described in Thompson (2006), Cohen's d was converted to an attenuated effect size d*. The adjusted (for pretest scores) group mean difference estimate without measure error correction for the posttest scores and the pretest scores was 4.2 with a Cohen's d = 3.04. An alternate approach reported in Cho and Preacher (2015) [7] was used to determine effect size. The adjusted (for pretest scores) group mean difference estimate with measurement error correction only for the posttest scores (but not with measurement error correction for the pretest scores) was 4.99 with Cohen's d = 3.61. Finally, the adjusted (for pretest scores) group mean difference estimate with measurement error correction for both pretest and posttest scores were 4.23 with Cohen's d = 3.07. The effect size indicates a strong relationship between the experimental intervention provided and students' conceptual understanding of chemical equilibrium concepts.

Keywords: chemical equilibrium misconceptions, chemistry dynamic simulations, chemical concepts, conceptual understanding, Le Chatelier's principle

Introduction

Learning chemical equilibrium, or even chemistry for that matter, entails understanding chemical phenomena at three levels: the system's macroscopic, microscopic and symbolic levels. A learner must also make coherent connections between the three levels (Johnstone, 1993) [17]. Learning difficulties typically arise when students move from macroscopic to microscopic and symbolic representations of chemical reactions, as these levels are abstract. While students who struggle to make connections between the three levels may experience a cognitive overload in their working memory, experts practicing chemistry can move through all three levels with a great deal of fluidity (Johnstone, 1993) [17]. Students could use an algorithmic approach to solve chemistry problems without demonstrating a clear conceptual grasp of the subject (Gabel, 1981) [10]. The preconception about equilibrium is based on the notion that it entails the equality of the opposing sides, stability, and being static in nature (Schafer, 1984). Even though systems that reach chemical equilibrium may appear macroscopically static, they are actually dynamic when viewed at the molecular level. Hackling and Garnett (1985) [12] categorized the seven main misconceptions about chemical equilibrium that frequently arise among students using data from their study. They are as follows: a) approaching equilibrium; b) equilibrium properties; c) altering equilibrium conditions; d) reaction rate effects; e) reaction rate as equilibrium is being restored; f) equilibrium constant; and g) catalyst effect. Student misconceptions may be exacerbated by instruction that places an excessive emphasis on students providing the correct response on a test without pointing out conceptual errors (Bergquist and Heikkinen, 1990) [2]. Students believed that once equilibrium had been reached, the rates of the forward and reverse reactions would vary (Huddle and Pillay, 1996) [15]. Additionally, according to several studies (Demirciolu *et al*., 2013; Heeg *et al*., 2020; Jusniar, Effendy, Budiasih, & Sutrisno, 2020; Üce & Ceyhan, 2019) [13, 14, 18, 28], students believe that the amounts of reactant and product are equal.

Omilani *et al*. (2020) [23] examined various viewpoints on chemical equilibrium. According to the findings, the majority of students are mistaken about a number of concepts, including a) adding a catalyst, b) the equilibrium constant (K), c) heterogeneous equilibrium, d) how to approach chemical equilibrium, and e) incorrectly applying Le Chatelier's principle. studies also found misconceptions about temperature changes and reaction enthalpies. Students failed to understand how enthalpy affected the reaction equation or system temperature (Indriani, Suryadharma, & Yahmin, 2017) [16]. Students disregarded any changes in temperature that might have an effect on how the molecules of the reactant and product are distributed (Yan & Subramaniam, 2018; Siswaningsih, Nahadi, & Widasmara, 2019; Ganasen & Shamuganathan, 2017) [31, 26, 11]. Previous studies on changes in the equilibrium constant revealed misconceptions. According to student predictions (Ganasen & Shamuganathan, 2017; Siswaningsih *et al*., 2019; Usu *et al*., 2019) [26,], changes in the reactant's or product's volume, pressure, and concentration will influence the shift in equilibrium. It's a common misconception that adding a catalyst to an equilibrium system will change the concentration of the reactant or product. (Heeg *et al*., 2020; Jusniar *et al*., 2020; Siswaningsih *et al*., 2019; Üce & Ceyhan, 2019) [14, 18, 28, 26]. Although solid concentration is always constant, students believe Le Chatelier's principle can be used to describe any system, including those in heterogeneous equilibrium (Banerjee, 1991; Heeg *et al*., 2020; Kousathana & Tsaparlis, 2002; Yan & Subramaniam, 2018) [1, 14, 31, 19]. The idea that the equilibrium will change in favor of more products when solids are added to the reactant side is a common one (Banerjee, 1991; Jusniar *et al*., 2020; Kousathana & Tsaparlis, 2002; Kurniawan *et al*., 2020) [1, 19, 18, 20]. Students frequently ignore the heterogeneous equilibrium system and the concentration of added substances (Heeg *et al*., 2020; Indriani *et al*., 2017) [14, 16]. Hackling and Garnett (1985) [12] and Crosby (1987) [8] noted that students believe the forward reaction ends before the reverse reaction begins. Students frequently held the belief that the concentrations of the reactants and products must be equal at equilibrium.

Visualization and Chemistry Learning

According to the research studies mentioned above, students' struggles with chemistry concepts are largely caused by their use of static models. A multimedia tool that combines text, videos, graphs, etc. can greatly reduce the conceptual difficulty that students face while learning chemistry concepts. Wu and Shah (2004) proposed five design tenets that should be taken into consideration when creating a visualization tool. Tenet includes a) multiple representations; b) tying visual and conceptual elements; and c) giving chemical phenomena a dynamic representation. d) transition between 2D and 3D structures; and e) easing cognitive load. Schnotz's integrated model of text and picture comprehension (IMPTC), which was used as the multimedia framework for the study, is one of many theories (Sweller, 1994; Mayer, 2002; Van Merrienboer & Kester, 2006) [27, 21, 29] that address the impact of multimedia learning on students' cognitive capacity. Working memory, sensory registers, and long-term memory make up the three main parts of the model's cognitive architecture (Schnotz, 2005) [25]. The IMPTC model also includes two additional levels: a cognitive level and a perceptual level, which is in stark contrast to other multimedia theories on cognitive capacity. The primary function of the perceptual level is to use sensory registers to transfer data from an incoming stimulus to working memory. The cognitive level is concerned with organizing data in working memory and storing it in long-term memory for later access (Schnotz, 2005) [25]. The IMPTC model also presupposes that pictorial information is sensed through sensory modalities other than vision, such as audio or sound images (Schnotz, 2005) [25].

A review of empirical studies on the use of computer animations in chemistry classes was done by Sanger (2008, 2009). The findings highlight the following major concepts: a) Students who used computer animations to learn chemistry concepts at the microscopic level had fewer misconceptions; b) a student's conceptual understanding and performance on exams improved; c) in contrast to static images typically seen in power point presentations during lectures or in textbooks, students who explored concepts using computer animations understood ideas at the microscopic, macroscopic, and subatomic levels. According to Yezierski and Birk (2006) [32], atomic and molecular-level animations helped students create more accurate mental models of particle characteristics and behaviors. Interactive simulations can provide dynamic access to various levels of representation by making objects visible that the human eye could not directly see (Ganasen & Shamuganathan, 2017; Moore, Chamberlain, Parson & Perkins, 2014; Watson, Dubrovskiy & Peters, 2020) [11, 22, 30].

Conceptual Framework

The complex systems theory of Brown & Hammer (2008) served as the study's conceptual foundation. Chemical equilibrium is a dynamic process, meaning that changing one variable during a chemical reaction can have a big impact on other variables in the system. As a result, a theory that uses a system's perspective will be taken into consideration for the study. A system is a collection of interconnected components. One variable in the system may be affected by a change occurring in another, which may then have an impact on the system's primary component where the change was initially induced. Inherent dynamism, non-linearity, emergent structures, and embeddedness are the four main factors that make up complex systems. Systems theory components were thoughtfully woven into the simulations during their construction.

Methodology

Research questions

1. What key characteristics of students' mental model regarding chemical equilibrium concepts can be extracted from student writings, drawings, and oral explanation before and after viewing simulations?
2. What evidence is observed to suggest changes in students' mental models on chemical equilibrium after they use the chemical equilibrium simulations?
3. After adjusting for pretest results, is there a statistically significant difference in the posttest means between the experimental group and the control group?

Research hypothesis

After adjusting for the pretest results, there will be a mean difference in posttest scores between the control and experimental groups.

Mixed methods design

An explanatory sequential mixed-methods design was adapted for the current study. Quantitative findings by themselves, however, won't be sufficient to understand how the findings happened. Therefore, gathering qualitative data that would explain the results from the quantitative phase would be the next logical step in the sequence (Creswell, 2015). Figure 1 represents the mixed methods design used in the study. After obtaining approval from the course instructor, the researcher met participants in person during class and explained the details of the study. Participants also received a briefing on the institutional review board (IRB) procedure.

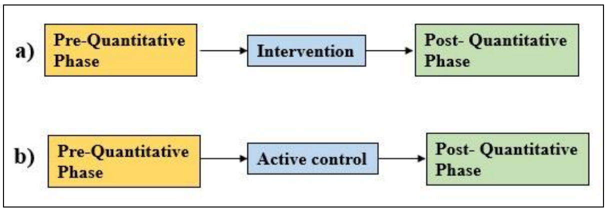

Fig 1: Mixed-methods design

Interview protocol

The interview process was semi-structured. A semi-structured interview, according to Patton (1990), is a procedure in which the tasks and the list of interview questions are predetermined, but the presentation order is not decided upon in advance of the interview. Tentative interview questions included a)Which part(s) of the simulation did you like best?,b)which element(s) of the simulation did you find the least appealing?,c)Which element(s) of the simulation could be made better?,d)Which element(s) of the simulation did you find to be the most useful?,e)Are there any specific questions on the quantitative instrument that, in terms of readability and clarity, you would have trouble understanding?,f)Explain your reasoning for selecting the response you did (this question will be repeated for incorrect responses). If there was a change in the correct response on the post-test, we asked the student why. Note: While interview responses from participants in the control and experimental groups were collected, only representative post-intervention responses from participants in the experimental group were presented for discussion. The Chemical Equilibrium Misconception Test (CEMT) was developed to identify student misconceptions. In lieu of space, the CEMT instrument will be provided on request and can be included as supporting documentation.

Instrument Reliability

The quantitative data from the CEMT test, pre- (control and experimental), and post- (control and experimental), were subjected to a Kuder-Richardson (KR-20) analysis to determine reliability. KR-20 analysis of the CEMT instrument is shown in Table 1.

Table 1: KR-20 Reliability Analysis

		N	%
Cases	Valid	27	100.0
	Excluded[a]	0	.0
	Total	27	100.0

Listwise deletion based on all variables in the procedure.

Cronbach's Alpha	Number of items
0.708	11

	Intraclass Correlation[b]	95% Confidence Interval F Test with True Value 0					
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	0.181[a]	0.088	0.336	3.428	26	260	.000
Average Measure	0.708[c]	0.513	0.848	3.428	26	260	.000

a. The estimator is the same, whether the interaction effect is present or not,

b. Type c interclass coefficients using a consistency definition. The between measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent because it is not.

Table 2: Conditional validity measurement

Items	E1	E2	E3	E4	E5	E6	E7	#of expert agreement	ICVI	Pc	K	A	A!	(N-A)!
1	1	1	1	1	1	1	1	7	1	0.0078	1	7	5040	1
2	1	1	1	1	1	1	1	7	1	0.0078	1	7	5040	1
3	1	1	1	1	1	1	1	7	1	0.0078	1	7	5040	1
4	0	1	1	1	0	1	1	5	0.71	0.1641	0.66	5	120	2
5	1	1	1	1	1	1	1	7	1	0.0078	1	7	5040	1
6	1	1	1	1	1	1	1	7	1	0.0078	1	7	5040	1
7	1	1	1	1	1	1	1	7	1	0.0078	1	7	5040	1
8	0	1	0	1	1	0	1	4	0.57	0.2734	0.41	4	24	6
9	1	1	1	1	1	1	1	7	1	0.0078	1	7	5040	1
10	1	1	1	1	1	1	1	7	1	0.0078	1	7	5040	1
11	1	1	1	1	1	1	1	7	1	0.0078	1	7	5040	1

N = 7; N! = 5040; E1-E7 corresponds to experts 1-7, pc -probability of chance agreement; K = kappa statistic.

Instrument Validity

A group of seven experts completed the content validity of the CEMT instrument. On a scale from 1-4, experts graded each test item. The CEMT's content validity was evaluated using the following criteria: The three factors are: a) item level of representativeness in measuring the aligned overarching construct; b) item importance in measuring the aligned overarching construct; and c) item level of clarity in measuring the aligned overarching construct (with four being the clearest). The CEMT was tested to determine whether the reading difficulty was appropriate for college students. The 27 students were instructed to circle any terminology they didn't understand. Content validation index (CVI) was calculated. The rating was either 1 or 0, depending on the relevance scale that was applied. 1 corresponded to relevance on scales of 3 and 4, and 0 to relevance on scales of 1 and 2. The total number of experts was divided by the number of experts who gave a rating of 3 or 4 to arrive at the I-CVI. For instance, a product with an I-CVI of 0.80 will receive a rating of 3 or 4 from four out of five experts. Polit and Beck (2006) [24] recommend a CVI value of 1 for teams of three to five experts.

Researchers frequently assess content validity using CVI. However, it does not take into account the possibility of inflated values brought on by unlikely agreements. By removing any random chance agreement, the Kappa coefficient calculation ensures a better understanding of content validity. The probability of chance agreement must be calculated using the Kappa statistic, which is Pc = [N! / A! (N - A)!]. 0.5N. This equation takes into account both the total number of experts on the panel, N, and the total number of experts who concur that the subject is crucial, A. In order to calculate the kappa statistic, use the formula K = (I-CVI - Pc) / (1 - Pc). One item received a rating of 0.6 and was deemed to be good, while another received a rating of 0.44 and was deemed to be fair. The kappa values for nine out of the eleven items were higher than 0.74, or 1.00. This demonstrates the test's strong content-related validity in evaluating students' misconceptions about chemical equilibrium. Table 2 presents the instrument validity results.

Computer Simulations

The simulations were made specifically for the study by the author using the SCRATCH® program developed at the Massachusetts Institute of Technology (MIT), Cambridge, MA. Since chemical reactions typically involve reactants and products within a single system, the idea of a separate two-piston system (reactants and products) may be controversial. It was deliberate to use a two-piston system. Part of the purpose of this design was to show students that reactions can still happen both forward and backward even after a system has reached equilibrium. So even after a system reaches equilibrium, reactants and products keep forming. The tunnel in the middle of the two pistons resembles the double-headed arrow that is typically observed in a system in chemical equilibrium. The narrator will read a disclaimer before each simulation begins. The disclaimer gives users details defending the rationale behind the two-piston system design. A chemical reaction or series of reactions can only be supported by one system, as is understood by students. The 12 simulations' goals and the concept upon which they were based are listed in Table 3 respectively. Start, stop, reset, play, pause, and mute buttons were present on every simulation. All simulations, with the exception of Simulation 5, were built around the chemical reaction shown in Equation 1 below. In lieu of spaces, only representative figures of simulations are shown below.

$$2NO\ (g) + Cl_2\ (g) \longrightarrow 2NOCl\ (g) \ \ldots\ldots \text{ equation 1}$$

In the system shown in equation 1, chlorine (Cl2) is a yellow gas, and nitric oxide (NO) is a colorless gas. The final product is a light yellow gas called nitrosyl chloride (NOCl). When the system is in equilibrium, participants can observe how the reaction continues to occur in either direction. Simulation 2 is displayed in Figure 2. By switching the lens on and off, participants could view the microscopic world through the macrosystem. Students will gain an understanding of why, despite appearing macroscopically stable and static, systems that reach chemical equilibrium are dynamic at the microscopic level due to molecular movement and the ongoing process of bond creation and breakage. Simulatin # 3 represents a system achieving chemical equilibrium in the microscopic mode. In addition to showing a system reaching chemical equilibrium from a microscopic perspective, simulations #4 (Figure 3) and # 5 (Figure 4) graphically display concentration as a function of time and the rate of the reaction, respectively. An analogy model representing equilibrium constant iks expressed by simulatino # 6.

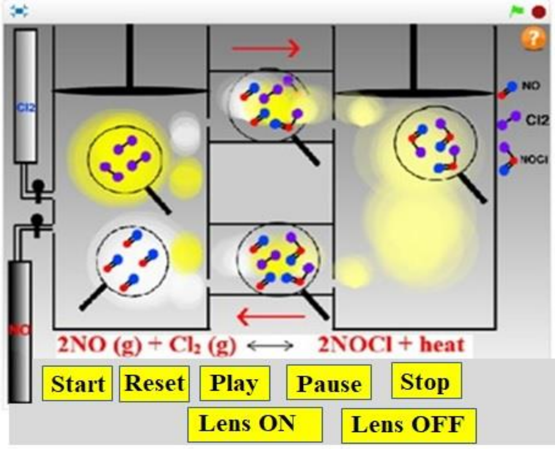

Fig 2: Microscopic view of the system using the lens option (Simulation # 2)

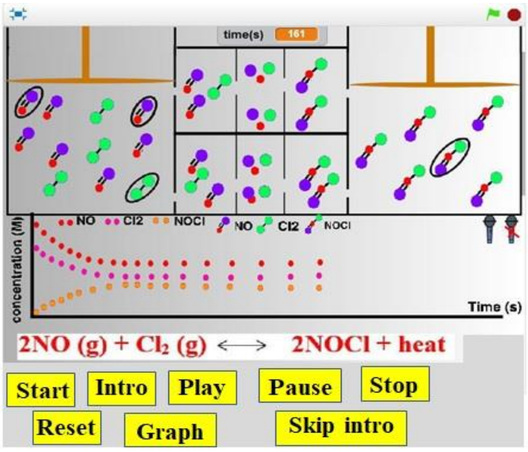

Fig 3: Concentration versus time (Simulation # 4)

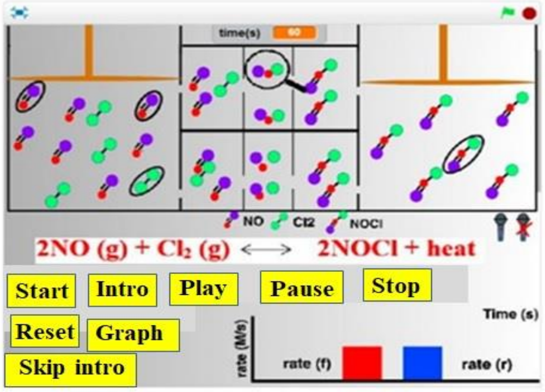

Fig 4: Rate versus time (Simulation # 5)

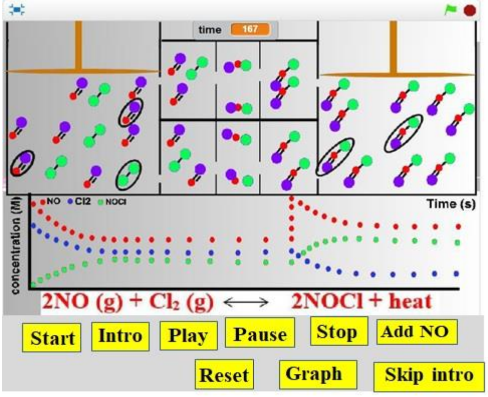

Fig 5: Effect of addition of NO (Concentration vs time) (Simulation # 8)

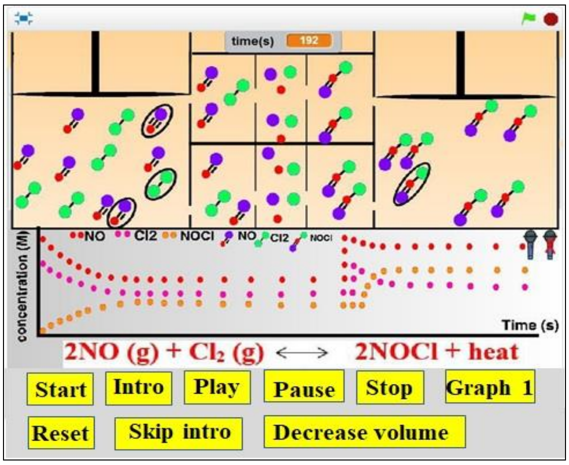

Fig 6: Decrease in volume of the system (Concentration vs time) (Simulation # 11)

The equilibrium constant was simulated by the conventional two-body pulley experiment on an inclined ramp. In the post-interview surveys, participants ranked simulation #5 as their favorite out of all 12 simulations. Simulation 7 is made up of two parts. The system achieves equilibrium in the first part. In part 2, by raising the level of nitric oxide (NO), participants can perturb the system's equilibrium. The concentration and rate fluctuate as the system returns to equilibrium in simulations # 8 (Figure 5) and #9. Two components made up Simulation #10. The system achieves equilibrium in the first part. In part 2, by decreasing the volume of the system, participants can perturb the system's equilibrium. The concentration and rate fluctuate as the system returns to equilibrium in simulations #11 (Figure 6) and #12.

The students took the pre-test in the first session. The participants completed the CEMT pre-test on average in 20 minutes. After finishing the pre-test, the students wrapped up the qualitative interview session. The second session of the intervention was completed by participants in the experimental group. Participants completed the post quantitative and qualitative assessment following the intervention after a 30-minute break. The intervention took between 90 and 110 minutes to complete. Students in the control group met for a total of about 90 minutes over the course of two sessions. Each student spent roughly 20 to 30 minutes during each session. They had the choice to go over their notes on chemical equilibrium or the material in the course textbook before taking the post test.

Table 3: Simulation Sequence.

Simulation #	Concept	Notes
1	Concept of chemical equilibrium	Macroscopic view of the system
2	Concept of chemical equilibrium	Microscopic view of the system
3	System at equlibirum	A system that's attained dynamic equilibrium
4	Concentraiton and particle mode	Change in contration & graphical representation of concentraion vs time
5	Rate and particle mode	Change in concentration & graphical representation of rate of the reaction
6	Two body pulley experiment	An analogy model demonstration equilibrium constant K
7	Effect of concentration	Microscopic view of concentration change
8	Effect of concentration	Change in contration & graphical representation of concentraion vs time
9	Effect of concentration	Change in concentration & graphical representation of rate of the reaction
10	Effect of volume	Microscopic view of concentration change
11	Effect of volume	Change in contration graphical representation of concentraion vs time
12	Effect of volume	Change in concentration & graphical representation of rate of the reaction

Results

Pre-Quantitative data analysis

A higher percentage of students had misconceptions about items 1 (27%, 42%), 3, (27%, 33%), 5, (40%, 50%), 8, (87%, 25%), and 10 (60%, 25%) that were frequently cited in the literature. A common misunderstanding among students, as per the literature, is that reactant and product concentrations are equal at equilibrium (items 3 and 5). The premise of equilibrium is that there must be two sides that are equal, stable, and static in nature. In everyday life, many people hold this belief. Chemically balanced systems may appear macroscopically stable and static, but they are dynamic due to molecular movement and the ongoing process of bond formation and breakage. Gussarsky and Gorodetsky (1990) claim that chemical equilibrium is misunderstood when macroscopic properties are applied at the microscopic level.

Responses to item #5 indicated that 50% of students in the control group and 40% of students in the experimental group thought that because NO and NOCl coexist in a 2:2 stoichiometry, the concentration of NO and NOCl at equilibrium must be equal. Bilgin (2002) [3] asserts that rather than comprehending the rules they are taught, students attempt to apply them by memorization. The root of the error, particularly for item 5, was discovered to be taking co-efficients into account in a chemical reaction.

For item 8, 40% of students in the control group and 33% of students in the experimental group incorrectly applied the stoichiometric and Le Chatelier principles. Students must decide in response to question 8 whether the equilibrium constant will rise, fall, or stay the same as the nitric oxide

(NO) concentration rises at equilibrium. Participants generally agreed that as more NO is introduced into the system, the reaction will shift to the right because there are fewer moles there, resulting in an increase in NOCl concentration and a decrease in NO and Cl_2 concentration. Similar results were reported by Hackling and Garnett (1985) [12] and Hameed *et al*. (1994) in their respective studies. They claimed that students in their study only took into account changes in NOCl concentration and ignored changes in NO and Cl_2 species concentrations. Students wouldn't be able to approach a chemical reaction from a systems perspective if they didn't understand the relationship between the quantities of reactants used and products produced in a chemical reaction. Students wouldn't be able to approach a chemical reaction from a system's perspective if they didn't understand the relationship between the quantities of reactants used and the products produced in a chemical reaction. For item 9, 33% of students in the control group and 47% of those in the experimental group had the false belief that as the system's volume is reduced, the forward reaction rate rises and the reverse reaction rate falls. According to Hackling and Garnett (1985) [12], the students' erroneous belief that reaction rates changed to support LCP-based predictions was the cause of the misconception.

The three items that participants had the most additional misconceptions about were items 6, 9, and 11. Twenty-five percent of students in the control group and twenty-five percent of students in the experimental group disagreed with the statement in item 9 that the rate of reverse reaction decreases as the system volume is reduced. With regard to item 6, 33% of respondents in both groups disagreed, believing that the equilibrium constant K would be less than 1. The majority of students (Hackling and Garnett, 1985) [12] held a qualitative perspective on how reactant and product concentrations changed as the reaction drew closer to equilibrium. Students believe that while the rate of a reaction in the reverse reaction decreases, the rate of a reaction in the forward reaction increases. The incorrect application of Le Chatelier's principle only serves to strengthen this misconception. Because of the ongoing emphasis placed in classroom instruction on the notion that when a system's volume is decreased, the reaction will shift to the side with the fewest moles.

Le Chatelier's principle has been applied incorrectly, as shown by Item 11. If the volume of a system at equilibrium is reduced, according to 42% of control group students and 67% of experiment group students, the concentrations of NOCl and Cl2 will be different from the initial equilibrium. According to Cheung (2009) [6], students are frequently asked to forecast the direction of an equilibrium shift during class discussions of chemical equilibrium involving LCP.

Post-Quantitative data analysis

For item 1, 42% of participants in the control group and 7% of participants in the experimental group thought that as the system gets closer to equilibrium, the rate of the forward and reverse reactions remains constant. In the experimental group, the percentage of participants who have misconceptions has decreased from 27% to 7%. For item 3, 33% of students in the control group and 7% of students in the experimental group still believed the widely held fallacy that the concentrations of reactants and products are equal at equilibrium. Only one student (7%) in the experimental group shared this misconception, as opposed to the same number of participants in the control group.

A common misconception about item 5 is that NO and NOCl concentrations are equal. According to the pre- and post-test results, 40% of the experimental group's students and 50% of the control group's students shared the same misconception. Pre-testing revealed that, for item 8, 40% of students in the experimental group and 42% of students in the control group agreed with the common fallacy that, when equilibrium is restored after a decrease in the system's volume, the equilibrium constant K will be higher. 40% of students in the control group and 33% of students in the experimental group still held this misconception on the post-test. On item 6, participants of the experimental group showed the smallest performance gain. 42% of students in the control group and 47% of students in the experimental group believed that K is less than 1, believing that there are fewer total moles of products at equilibrium.

In response to item 11, 83% of students in the control group and 13% of students in the experimental group believed that when a system's volume is reduced at equilibrium, NO and Cl2 concentrations will be lower and conception of NOCl will be higher as the system's equilibrium is restored. According to Hackling and Garnett (1984), students who shared this misconception were not fully aware of the connection between the consumption of reactants and the production of products during chemical reactions. Improper LCP application can result in inaccurate results (Cheung, 2004) [5]. Multiple-choice answers were frequently selected by students on a test about chemical equilibrium without corresponding levels of understanding for the underlying concepts (Berquist, 1989).

In the experimental group, 93% of participants responded correctly to item 1, while only 17% of participants in the control group did so. Only 25% of those in the control group and 33% of those in the experimental group had the correct response to item 1 on the pre-test. The number of students who had the correct answers increased significantly between the pre- and post-test, as evidenced by the percentage comparison between the two. In the experimental group, 93% of participants held correct response for item 3, compared to 50% in the control group. The percentage of participants in the experimental group who provided the correct rose noticeably. Regarding item 5, 93% of those in the experimental group and 50% of those in the control group respectively gave the correct response. For item 10, 87% of the experimental participants and 0% of the control group members provided the correct response. The proportion of students in the experimental group who held correct response has significantly changed, whereas there has been no change in the control group. In the case of item 11, 60% of participants in the experimental group and 0% of those in the control group correctly answered. The proportion of students in the experimental group who held correct response has significantly changed, whereas there has been no change in the control group.

ANCOVA analysis

An ANCOVA analysis was carried out to test research question 3 and the study's research hypothesis.

Research Question 3

After adjusting for pretest results, is there a statistically significant difference between the posttest means for the experimental group and the control group?

ANCOVA

By accounting for variations in the covariate, a one-way analysis of covariance (ANCOVA) establishes whether population means on a dependent variable are the same across levels of an independent variable (i.e., whether the adjusted group means differ significantly from one another). The covariate and dependent variable make quantitative distinctions between individuals while the independent variable divides people into two or more groups. An ANCOVA is used to compare the posttest results of the two groups (control and experimental) after subject heterogeneity, or naturally occurring individual differences, have been taken into account.

ANCOVA Results

After adjusting for pretest scores, the results of a one-factor ANCOVA revealed that posttest scores were significantly higher for the experimental group than the control group (Mpostadj. = 7.27, SDpost = 1.387): F (1,24) = 71.82, MSE = 1.497, p = 0.03, p2 = 0.75, d = 3.33. Cohen's d was transformed using the method described in Thompson (2006) into an attenuated effect size d*. Without accounting for measurement error, the adjusted group mean difference estimate for the post-test and pre-test scores was 4.2 with a Cohen's d of 3.04. The effect size was calculated using a different approach described by Cho and Preacher (2015) [7]. With Cohen's d = 3.61, the estimated adjusted group mean difference between the post- and pre-test scores was 4.99. Finally, for both the pretest and posttest scores, the adjusted (for pretest scores) group mean difference estimate with measurement error correction was 4.23 and Cohen's d = 3.07. The effect sizes show a significant correlation between the offered intervention and students' conceptual grasp of chemical equilibrium ideas. In other words, participants who received the intervention had incredibly high CEMT scores.

Qualitative Interview Analysis Responses (Experimental Group)

Item 3

In the experimental group, 14 out of 15 participants held a system view of chemical equilibrium after the intervention. The italicized words emphasize a change in the participant’s mental model. The rate of a reaction in an equilibrium system is described in Item 3. To understand the concept of rate, it is crucial to understand the concept of dynamic nature. (R – researcher and P – participant)

Representative student response (post intervention)

R: Okay for #3, you may have changed your answer, that does not mean it’s right or wrong? For # 3 you choose (a), on your post-test you decide to go with (c), why is that?

P: I kinda realize, after seeing the graph, the reactants aren’t going to be the same at equilibrium, so K very might well equal 1, not because products, I mean concentration of 153 products and reactants may not be the same, its just K expression is equal to 1, because its

R: So why do we say K equals 1. I mean, I really understood your logic, If in algebra we say, the ratio equals 1, what do we assume?

P: Well, if you assume, your ratio is 1, you have the same amount on one side and the same on the opposite side.

R: So if we say its constant as in (c), right, but we say equilibrium means K equals 1, what are we really refer to, these two cannot be equal, than how can K be equal to 1?

P: I would say the ratio of going from one end to the other is the same

R: so what is that ratio called? it’s called by a different name.

P: May be rat*e?*

Item 4

In the experimental group, all 15 participants held a system view of chemical equilibrium after the intervention. The italicized words emphasize a change in the participant’s mental model. After the intervention, students not only held a dynamic view of the rate concept but also had a stronger conceptual understanding.

Representative student response (post intervention)

R: Okay for #4, you went with (b) on your pre-test and this time around you decide to go with (f), what was your reasoning?

P: Cuz, once its done

R: You mean it attained equilibrium

P: Yeah, that’s what I mean

P: I mean, once its done, its basically gonna be levelled out, that’s what, I get it now, when it meant by constant over time, that’s why I decide to with (c), this time around.

P: I can also see, the reaction continue to occur, so (f) makes the most sense

Item 10

In the experimental group, 13 out of 15 participants held a system view of chemical equilibrium after the intervention. The italicized words emphasize a change in the participant’s mental model. Because molar concentration is the ratio of moles of solute over the total volume of the system, the underlined words imply that the students have a system's perspective, i.e., that concentration of all species would increase if volume of the system were to decrease.

Representative student response (post intervention)

R: *For #10, you indicated (c) as your choice, this time you decide to go with (f), what was your reasoning behind the change?*

P: Okay when new equilibrium is re-established after decreasing the volume, which means you increase the pressure, rates of forward and reverse reaction will be greater than before, so,

R: Why do you think its greater?

P: Rate = k*times.

P: I don’t think that’s right,

R: No go ahead and complete it, this is one way of writing it

R: So how did we define rate earlier in our interview?

P: We said concentration over time

R: Why do you think rate is greater, what made rate greater?

P: more stress on reactants and products, to compensate, subsequent increase in NOCl, there is also going on in the reverse direction,

R: So what is increased in the ratio?

P: The concentration of the products and the reactants?

R: Very good, good

Conclusion

Figure 7 displays participants' correct beliefs both before and after the study for the experimental and control groups. The percentages of correct responses for the pre- and post-test are shown inside the brackets. The experimental group students provided a higher percentage of these answers. The highest scores were awarded to items 1 (33%, 93%), 3, (60%, 93%), 4, (53%, 100%), 5, (20%, 67%), 7, (7%, 47%), 10, (20%, 87%), and item 11 (27%, 60%). Participants saw only slight improvements with items 6, 8, and 9. The conceptual understanding of chemical equilibrium concepts was significantly improved in the participants who underwent the experimental intervention.

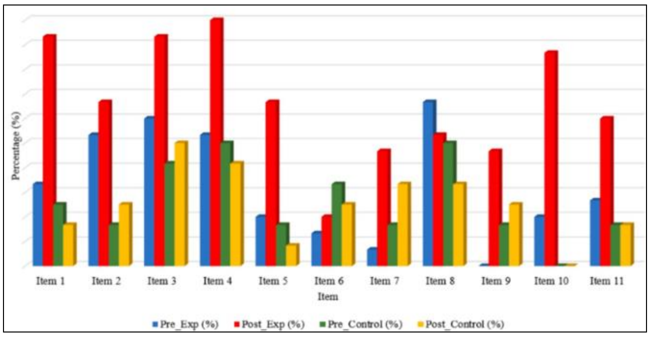

Fig 7: Graphical depiction of the pre- and post-phase participants in the control and experimental groups' percentages of correct conception.

The study's results were positive and backed up the aim of determining how well a simulation could aid students' conceptual comprehension of chemical equilibrium. According to statistical significance from the independent samples t-test, the intervention appears to have had a significant impact on students' conceptual understanding of the chemical equilibrium concepts discussed in the study. The validity of the quantitative CEMT instrument is supported by its reliability, which is alpha = 0.71.

Significance

a) This study's approach to chemical equilibrium using visual technology is its main point of significance. Despite the fact that the numerous research studies mentioned above have revealed widespread misconceptions about chemical equilibrium among students, no study has examined chemical equilibrium from the perspective of a system, b) The simulations used in this study model a chemical reaction at the particle level and feature graphs that allow students to relate the data to the progress of the reaction. Students have the opportunity to interact with the technology through the simulations, and c) The simulations that have been made have both audio and visual components. The simulations can therefore satisfy the needs of students who prefer to learn visually, aurally, or both.

Limitations

a) The study only examined students' false beliefs about a more limited number of chemical equilibrium concepts. As a result, the results of the study cannot be used to deduce ideas or misunderstandings that students may have regarding other chemical equilibrium or chemistry concepts, b) The study's main limiting factor was time. This includes the time it took to find students to fill in the required sample size for the research study as well as the pilot study, as well as the time each participant was willing to devote to the study, c) Limitations of interpreting qualitative interviews include a) how the questions are cued - was there unintentional prompting; b) the possibility that the researcher's presence will alter the student's response; c) concept modification during the interview; and d) the degree of the student's conviction in their answers. For example, if the student was asked to write their justification for their answer choice rather than just state it verbatim, they might have chosen a different justification.

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