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The Effect of 'box-and-bead' Analogy versus Retrieval-based Learning on Retention in Chemical Kinetics among First-Year Chemistry Students

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Abstract. The study examined the effects of the box-and-bead analogy versus retrieval-based learning on students' retention and performance in chemical kinetics among first-year chemistry students. A purposive sampling technique was used to sample participants from the accessible population. The sample was made of two hundred and forty-five (n = 245) first-year chemistry students, at a public university, in South Africa. The study adopted a sequential explanatory research design. A chemical kinetics retention test (CKRT) was used for data collection as pre-, post-test and delayed post-test. A reliability coefficient of 0.73 was established using the Kuderson and Richardson correlation moment coefficient. Participants in the two groups were taught using an advanced retrieval instruction approach and the box-and-bead analogy. The results of the study showed no statistical difference in the retention of procedural knowledge and a statistical difference in conceptual knowledge. Overall, students taught using advanced retrieval performed better than the other group. The study underlines the fact that analogy-based instruction can be effective in improving conceptual knowledge using concrete analogues that aid in the retention of chemical kinetics. The findings of this study are diagnostic and they assist module designers in determining the procedural and conceptual knowledge in chemical kinetics retained by students, even after years have passed.

Keywords: analogy; base/target domains; chemical kinetics; cognitive load theory; retention; retrieval

1. Introduction

First-year, introductory physical chemistry is based on the three important topics of chemical kinetics, thermodynamics and basic quantum mechanics. Chemical kinetics is concerned about how fast a reaction progresses, through the monitoring of a suitable parameter which changes with time. Chemical kinetics relies heavily on complex mathematical concepts, such as differential equations in advanced courses, and students are expected to retain core knowledge concepts learned in their first year. The two instruction methods of retrieval-based learning and analogies might have the potential to enhance retention among university students. The retention of introductory physical chemistry concepts is vital for success in advanced chemistry courses in the third and fourth years. There has been growing concern about students' lack of retention of the important concepts that are required as pre-requisites for advanced modules in science, technology, engineering and mathematics (STEM). Lecturers of advanced courses in chemistry bemoan students' lack of recall of the core knowledge concepts learned in first year.

Third and four-year attrition is a long-established problem in South Africa, going back many decades. Specifically, there has been very little change since 2000 (Scott, 2014). The Council on Higher Education (CHE, 2013) reported that the greatest attrition occurs at the end of the third year of study. In 2014, the CHE report revealed that poor performance in STEM is still persistent across South African universities. Most of the degree completion rates are below 42% at contact universities. The high dropout and failure rates of students in second and third-year chemistry might be due to the poor retention of core knowledge concepts from preceding modules. This lack of retention of core knowledge concepts is not unique to South Africa. In the USA, Arum and Roska (2011) alerted institutions of higher learning about the lack of critical skills thinking and retention among STEM college graduates.

Chemistry as a discipline risks being a mnemonic exercise if students fail to retain core knowledge concepts that drive chemical phenomena. The retention of core knowledge concepts by students may be a research niche in science-education that has the potential to inform instructional practices at a tertiary level.

The new curricula for the Natural Sciences and Technology module focus on the relationships between the concepts and meanings behind procedures (CHE, 2016). Kieran (2013) suggested that a procedural and conceptual dichotomy is the distinction between knowing how (instrumental) and knowing how and why (relational). In chemistry, Zoller (2002) posited that procedural knowledge requires questions that use a memorised set of approaches for their solution, while conceptual knowledge invokes the fundamental concepts of the primary theories of science in order to answer the question. The distinction between being able to apply a relatively well determined set of instructions to a chemical problem and being able to explain and use links between different structural aspects of chemistry remains unexplored in chemistry education literature in South Africa.

Potgieter et al. (2006) investigated the procedural and conceptual knowledge in mathematics and chemistry in first year students at the University of Pretoria. The study was a correlation which sought to establish whether students who displayed good conceptual and procedural understanding in mathematics also performed well in chemistry. The findings revealed low relationships between performance in chemistry and mathematics. The authors suggested that it was an indication that students had more alternative conceptions in chemistry than mathematics. This study did not use different instructional methods and never went further to check the retention of concepts.

Lysne et al. (2017) defined retention as the ability of a student to remember what has been learned over time and it is influenced by instructional approaches.

Furthermore, retention is the extent to which students can successfully retrieve core knowledge concepts from long-term memory. Instructional methods play an important role in the retention ability of students. Inappropriate lecturing methods in chemistry invariably translate to students' inability to retain core knowledge concepts (Ajayi & Angura, 2017).

In South Africa, chemistry lectures are usually with very large classes. The traditional lecture method is the *modus operandi* and there are few lecturer-student and student-students' interactions. The long-term retention of first-year engineering students in the study of calculus was investigated over two years at the University of Pretoria in South Africa by Engelbrecht et al. (2007). A mixed-method research design, involving pre-test, post-test and interviews, was used to collect data among the first years. The same test was administered as a pre-test in the first year and, after two years, as a post-test. Participants were exposed to the traditional lecturer-centred instructional approach. The authors reported a decline in the retention of core knowledge concepts of calculus and performance. The findings may have been different if other instructional methods had been used.

In a related study, D'Ottone and Ochonogor (2017) investigated the effectiveness of problem-based learning (PBL) with simulations in retention of chemical kinetics concepts among 104 second-year chemistry students in the USA. A quasi-experiment, non-equivalent, Solomon four design was used to determine the performance and retention of the students. The findings of the study showed that students who were taught using simulations and PBL retained concepts better in the post-test than those taught using the traditional lecturer-centred instructional approach. The retention reported in this study was based on delayed post-test scores.

Didis (2015) investigated the effectiveness of analogies in introductory quantum theory among first-year chemistry students. The author observed 48 analogies and the data were collected through interviews and analysis of video recordings. A wide variety of analogies used during lessons included verbatim, pictorial and body motion. The analysis of the interviews showed that students enjoyed the analogies and it improved the conceptual understanding and retention of quantum theory concepts. The study recommended the use of multiple analogies in teaching abstract topics in chemistry. The findings focused on conceptual knowledge and left out the procedural knowledge.

Shahani and Jenkinson (2016) also explored the efficacy of interactive analogical models among third-year chemistry students. The study employed two analogies: the spring system and electrostatic spheres on potential energy curves. The results of the study showed that students had difficulties in visualising the potential energy wells and the post-test mean score increased by 11%. Retention in this study was also based on the delayed post-test scores.

Taylor et al. (2016) investigated first-year university students' retention of pre-requisite knowledge using activities and in-class reinforcement. The findings showed that pre-class activities, together with integrative questions, were effective in improving performance and long-term retention.

Karpicke and Blunt (2011) compared RELT and concepts maps in improving retention among high school students. The participants in the RELT group were given educational texts and practiced retrieval without looking at the text for three weeks. The final assessment was based on conceptual questions and the students performed better than those in the concept map group. RELT has a paucity in science education and its potential still remains unexplored. In a similar study, Chan and McDermott (2007) investigated the effectiveness of RELT on 48 undergraduate students. The students were tested on basic arithmetic and English. The findings revealed that students' retention improved.

This study seeks to explore how RELT can also improve retention in chemical kinetics. The retrieval-enhanced learning theory (RELT) underpins the act of bringing information from long-term memory. RELT approach is based on the assumption that all types of knowledge require retrieval and depend on the retrieval signal available in a given context. Furthermore, when an individual retrieves knowledge, that knowledge is altered, because retrieving knowledge enhances one's ability to bring it out again in future. Karpicke (2012) claimed that RELT does not simlpy produce rote and short-term learning but it enhances long-term learning. Retrieving information from the long-term memory improves retention and learning far better than reading and reviewing time and again (Karpicke, 2012; Butler & Roediger, 2008; Butler, 2010). Retrieval-based learning (RBL) is a powerful learning strategy that is under-appreciated and is not considered as an important part of the learning process by both educators and students (Karpicke & Bauernschmidt, 2011). The reason for that might be that educators confuse repeated retrieval learning and rote learning. Recent research on repeated retrieval on the spectrum of pre-school to high school has established that retrieval-based learning enhances retention (Balota et al., 2006; Fritz et al., 2007).

One modern theory of RELT is the episodic context account (Karpicke, 2012), which is based on four central assumptions. Firstly, individuals encode information in the temporal or episodic context in which they occurred. Secondly, during retrieval, the memory search process involves an attempt to reinstate the episodic context. Thirdly, if information is successful retrieved, the episodic context is updated and incorporate features of the new context. Finally, the updated context aids in recovery and successful retrieval enhances memory performance.

The episodic theory accounts for two important findings in the retrieval practice literature. Spaced retrieval improves retention as compared to massed retrieval (Roediger & Karpicke, 2011). Spaced retrieval yields updated context representations that are distinctive and easily accessed. Furthermore, the episodic context explains the role of a retrieval mode. Karpicke and Zaromb (2010) defined a retrieval mode as the cognitive state in which individuals intentionally think back to a particular place and time where an event occurred.

An analogy transfers a system of relationships from a familiar/base domain (box-and-bead analogy) to one that is less familiar/target domain (chemical kinetics). The chemistry conceptual understanding learning model, suggested by Johnstone (2009), claims that matter is represented at the three levels of macroscopic, microscopic (particles/molecules) and symbolic (chemistry language and mathematical models). Though students live in the macroscopic world, the chemical kinetics concepts require them to be versatile in both microscopic and symbolic levels. Thus, analogies bridge the gap among abstract concepts and familiar domains through a process called mapping. Matching or mapping involves finding correspondence between two domains.

The dynamic skill theory (DST) is an extension of social constructivism that claims that skills do not develop in a vacuum but are influenced by social factors (Fischer, 2008). Skills develop on three levels of increasing complexity, differentiation and integration, and are influenced by self, others and the environment (Mascolo & Fischer, 2016).

The DST also claims that cognition develops through levels and tiers. At the age of 14 - 18 years old, students operate in the abstract tier. In the abstract tier, there are three abstractions, namely single, mappings and systems. Mappings play an important role in analogy-based instruction since analogies uses similarities between the familiar and unfamiliar domain. One finding linked to the DST is that student performance does not increase steadily but is dynamic, depending on context.

The retention of concepts is influenced by the instructional methods and analogies bridge the gap between familiar and unfamiliar domains. Thus, instructional methods play an important role in the retention and performance of students.

While analogies and RBL have been studied in a variety of settings, very few studies directly show their effect on retention of chemical kinetics. Bain and Towns (2016) reviewed 34 peer reviewed science education journal articles on chemical kinetics. Most of the studies were based on conceptual understanding and alternative conceptions in chemical kinetics but very few where based on students' retention of chemical kinetics concepts. There is a paucity of research about the retention of core knowledge concepts in chemical kinetics at both the secondary and higher educational levels. This study investigated how two instructional methods affect the retention of conceptual and procedural knowledge and performance in chemical kinetics.

The study was guided by the following research questions:

1 Is there a statistically significant difference between pre-test and post-test scores of the students taught with the box-and-bead analogy and RBL instructional approaches?

2 What is the effect of lecturing with the box-and-bead analogy and RBL instructional approaches on first-year chemistry student's procedural and conceptual knowledge retention in chemical kinetics?

3 How does the box-and-bead analogy and RBL instructional approaches enhance retention of procedural and conceptual knowledge of chemical kinetics concepts among first year chemistry students?

1.1 Research Design

This study employed a mixed-methods, sequential, explanatory research design, which consisted of a dominant quantitative approach (quan) followed by a qualitative approach (qual) (Creswell, 2015). In this study, a quasi-experimental, non-randomised, pre-test-post-test post-post-test control group and semi-structured interviews were used in a sequential design. The reasoning for this approach is that the analysis of quantitative data provides a general apprehension of the research problem. Furthermore, analysis of qualitative data refines and explain statistical results by investigating the participants' perspectives in-depth. The overarching goal of quasi-experimental research lies in attempting to find the effectiveness of a treatment or intervention (Creswell, 2015).

1.2 Participants

The participants involved in this study were 245 first-year chemistry students (age range of 18-24 years) at a South African public university. Convenience sampling was used to select two groups which were readily accessible to the researcher. Two groups (A = 121 box-and-bead analogy) and (B= 124 RBL) were randomly assigned to experimental and control groups. All the students were enrolled in the Faculty of Education, Department of Mathematics, Science and Technology (MSTE).

The Natural Science and Technology module is divided into the two areas of Chemistry (50%) and Physics (50%) and had two instructors. The module is taken in three months in the first semester. First-year students enter directly from high school and the entry requirements include a pass in both Physical Sciences and Mathematics. The South African high school Physical Sciences Curriculum and Assessment Policy Statement (CAPS) has three topics under chemical change (rate and extent of reaction, measuring rates of reactions and mechanisms of reaction and catalysis) which are related to chemical kinetics.

Students were assessed through pre-, post- and delayed post-tests and interviews. An university ethical clearance was obtained to collect demographic information through tests and interviews. The study was guided by three ethical considerations: deception of the participants, protection of the participants from harm and confidentiality of data. The potential benefits of the study were explained to the students and consent forms were completed. Participants were assured that their individual scores would not be recorded as part of their official duly performed (DP) marks.

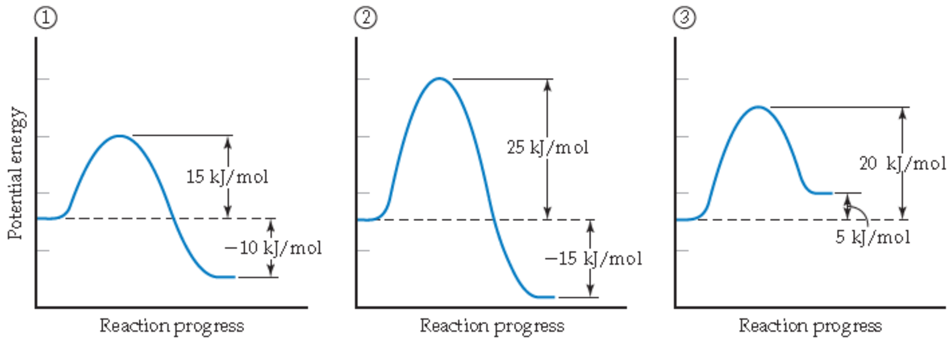
2. Data Collection Instruments

The first stage of the instrument development involved defining the content boundaries of chemical kinetics. The module outline of the first year module 'Introductory to Basic Chemistry' subtopic, 'Reaction Kinetics of Chemical Reactions', and South Africa's high school National Curriculum Statement (NCS) for the physical sciences (rate and extent of the reaction) were used to define the content scope of the study, encompassing reaction rates, factors affecting rates and experimental rate determination. The chemical kinetics concepts covered in the CKRT were the rates of chemical reactions, temperature and concentration, dependence on rate and order of reactions. The identification of alternative conceptions by reviewing literature was the second stage that was used to select distractors in the instrument. Accordingly, distractors in the multiple-choice questions were based on alternative conceptions related to chemical kinetics (Bain & Towns, 2016)

The CKRT was administered as a pre-test, post-test and delayed post-test. The test covered the core knowledge (conceptual and procedural knowledge) in chemical kinetics. Conceptual knowledge is based on concepts that drive factual pieces of information from the environment. Furthermore, it links key concepts and the relationships among them. It is a connected web of knowledge. Procedural knowledge includes knowledge of formal language or symbolic representations, and knowledge of procedures, rules, formulae, algorithms and symbols used in chemistry. Test items assessing conceptual and procedural knowledge are referred to as conceptual and procedural questions respectively. The CKRT had five two-tier multiple choice questions and reasoning and five open-ended questions (Figure 1). Three multiple-choice questions and two open-ended questions were based on procedural knowledge. In contrast, two multiple-choice questions and three open-ended questions were based on conceptual knowledge.

The three chemistry lecturers and three high school educators checked the content validity of the instrument. The reliability of the CKRT was calculated using Kuderson-Richardson 0.74. The difficult indices of the CKRT ranged from 0.31 to 0.64. A five-question, semi-structured, interview data collection instrument was used to gain insight into how the use of analogy and retrieval based instructional methods improves the students' retention of chemical kinetics concepts.

Question 1.8 Consider three reactions having the energy profiles below:



Arrange the reactions from slowest to fastest, assuming they have the same frequency factor A.

Two groups were instructed using the box-and-bead analogy (A) and RBL (B). Post-test mean scores were compared to the pre-test mean scores after a three-week intervention. The delayed post-test was administered after six-months. A total of 12 students were purposively selected for interviews after the delayed post-test.

The box-and-bead analogy suggested for this study was designed by the author. The activities involving plastic beads and shoeboxes were used to map abstract chemical kinetics concepts. A chemical kinetics analogy organiser was used to avoid the mechanical breakdown of the analogy by mapping the similarities and differences between the abstract and familiar domains. An analogy to represent a zero-order involved dividing the shoebox with cardboard, with a small opening at the bottom. The other side was filled with 20 beads and the students were to shake the shoebox. After two minutes, the students counted the beads that had crossed to the other side of the shoebox. The process was repeated with 100 beads.

Students used the analogy organiser to map the similarities between the familiar and unfamiliar domains. To illustrate the statistical approximation of the Maxwell-Boltzmann distribution curve, students placed 100 beads (50 red and 50 blue) into the shoebox and shook the contents. The students observed the movement of beads and mapped similarities with the target domain.

In a reaction, very few particles possess the right kinetic energy and orientation for a collision to form products. To witness the effect of temperature on the rate of reaction, students shook the beads inside the box gently, moderately and quickly. Students observed the movements of the beads and mapped the similarities.

For the progression of the rate of reaction, students used two boxes, one for reactants and one for products. A concentration versus time graph was used to follow the progression of the reaction. The beads were transferred from the reactants to the products and students mapped the similarities and differences between the familiar and target domains on the progression of rate.

The two groups met three days a week for the semester. The textbook used was *Chemistry Seventh Edition* by Zumdahl and Zumdahl (2007). Table 1 shows some of the mappings done during the lessons.

Table 1: Mappings between familiar and unfamiliar concepts

Familiar	Unfamiliar concepts
Beads	Molecules
Gentle shaking	Low temperature
Cardboard with a small opening	Zero-order (reaction independent of the concentration of reactants)
Movement of beads	Maxwell-Boltzmann distribution curve

Retrieval-based learning has five steps (Karpicke, 2012) namely, enhance metacognition, practice with real-world scenarios, provide multiple self-checks and exercises, space retrieval practice and provide opportunities for group discussions. The first step involves introducing RBL and its advantages to the students. One of the advantages is that it enhances learning and long-term retention by repeatedly practicing to recall the information studied (Karpicke, 2012). The university's learning management system (LMS) (moodle) was used to actively engage students with a quiz before they arrived for lectures. The pre-lecture quiz covered important pre-requisite concepts students had to remember.

Step two involved repeating step one, using isomorphic questions. To reinforce retention, students worked in pairs answering questions. Step three of providing feedback involved giving students flashcards to practice and the answers were posted on the LMS. To vary the retrieval steps one to three, students worked in groups and took online quizzes. The last step involved changing the questions from low to higher cognitive levels and the quiz questions were changed from simple recall to conceptual tests.

2.1 Method of Data Analysis

The data collected from students' pre-, post- and delayed post-tests were analysed using the Statistical Package for the Social Science (SPSS) version 25. The data collected through semi-structured interviews were analysed qualitatively using idiographic and nomothetic methods analysis. The interviews were recorded and transcribed. Measures of central tendency were used to analyse the students' performance between pre-test and post-test. One way Anova was used to analyse retention between the two groups.

3. Findings

The mean scores of the two groups were compared to investigate the effectiveness of the box-and-bead analogy and retrieval-based learning on students' performance in chemical kinetics. The descriptive statistics of the two groups are presented in Table 2.

Rutherford (2011) described how to analyse a non-equivalent pre-test post-test research design. The first step involves establishing equivalence among the groups. As can be seen from Table 2, the pre-test mean scores of the two groups are 56.90 % and 58.8% respectively, implying that the mean scores are equivalent. The post-test mean score of students taught using the box-and-bead analogy is 63.73% versus 65.34% of the RBL. The mean score for the post-test of RBL is slightly higher therefore the students performed better than those in group A box-bead-analogy.

The standard deviation (SD) measures the spread of scores and it is a square root of variance. The values of the SD of the delayed post-tests were 7.350 and 5.128 for group A and B respectively. A low SD suggest the scores are close to the mean and a high SD the scores are scattered from the mean. From descriptive statistics it can be concluded that a low SD suggest the post-test scores were close to the mean in RBL as compared to box-bead and box analogy.

Table 2: Descriptive statistics

Group	Pre-test	P-test	Delayed P-test	N	Sdpre	Sdpost
Expt A	56.90	63.73	56.25	121	6.989	7.350
Expt B	58.83	65.34	51.08	124	9.843	5.128

The null hypotheses H_{01} and H_{02} were tested to establish whether the difference between the two interventions was due to error or variance.

Table 3: One way ANCOVA analysis of the post-and delayed-post-tests mean scores of experimental and control groups

Variable	F	t	mean scores	Sig (2-tailed)
Delayed P-test	**0.686**	**-2.37**	**59.43, 56.21**	**0.018**
Post-test	**0.002**	**-2.908**	**63.73, 51.08**	**0.004**

The analysis of covariance (ANCOVA) on the two groups was done on the delayed post-test using post-test scores as a covariate. As seen in Table 3, the p-value obtained is 0.018 at 0.05 level of significance. The null hypothesis of no significant difference between performances of the two groups in the delayed-post-test is rejected. This implies that lecturing using the box-and-bead analogy is better at improving students' retention ability in chemical kinetics than retrieval-based learning. Similarly, the p-value obtained for the post-test score is 0.004 at 0.05 level of significance. The null hypothesis of no significant difference between the post-test score after instructional interventions with the box-and-bead analogy and retrieval-based learning is rejected. Thus, lecturing using retrieval-based learning improved student's performance better than using the analogy.

The analysis of the two groups on post-test and delayed post-post-test procedural and conceptual knowledge questions was done using quantitative item analysis, as shown in Table 4. Table 4 shows a decreasing trend in all of the groups after six months. Overall, retention was the highest in experimental group A and the least was in group B.

Table 4: Item analysis of post and delayed-post-test questions

	Post-test				**Delayed Post-test**			
	PK_A	CK_A	PK_B	CK_B	PK_A	CK_A	PK_B	CK_B
1.1	64	69	70	70	57	58	60	55
1.2	59	59	63	64	57	54	48	58
1.3	61	66	54	55	52	55	53	40
1.4	53	48	62	50	45	54	51	28
1.5	68	47	73	42	65	44	61	30

Key: PK_A - procedural knowledge group A

CK_A - conceptual knowledge group A

Rate of Chemical Reactions

Question 1.1 and 1.6 covered how the rate progresses during a reaction and how the rate of product and reactants relate given stoichiometry equations respectively.

Calculate the rate at which ozone is consumed as compared to that at which oxygen is produced in the reaction 2 O_3 (g) $\longrightarrow$ 3O_2(g)?

If the rate at which O_2 appears, 6.0 x 10^{-5} M/s at a particular instant, at what rate is O_3 disappearing?

The mean scores for question 1.1 were 64% and 70% in the post-test and 57% and 58% in the delayed post-test. There was a drop in the overall performance. For question 1.6, students claimed to have forgotten the formula and that the formula book could have helped. During interviews, students relied on calculators and the variation in the second part created some confusion. Thus, it can be concluded that students were procedurally proficient but lacked the conceptual knowledge on the rate of chemical reactions.

Temperature Dependency

For question 1.7, Table 5 shows the rate constants for the rearrangement of methyl isonitrile at various temperatures.

Table 5: Rate constants

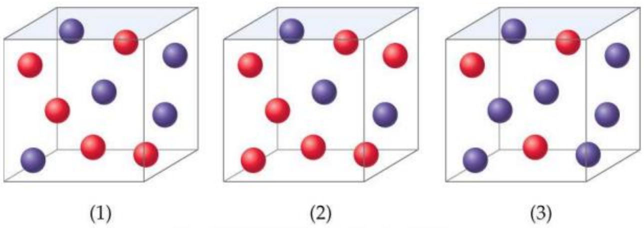
Temperature (°C)	$k\,(s^{-1})$
189.7	2.52×10^{-5}
198.9	5.25×10^{-5}
230.3	6.30×10^{-4}
251.2	3.16×10^{-3}

Students were required to calculate the activation energy for the reaction and also the value of the rate constant at 430.0K. The mean scores for the groups were 55% and 46% for the delayed post-test, and 66% and 55% for the post-test for groups A and B respectively. For this question, the retention was high using an analogy (group A) as an instructional method.

Question 1.5

Consider a reaction for which rate = k [A][B]^2.

Each of the following boxes represents a reaction mixture in which A is shown as red spheres and B as purple ones. Arrange the reactions in ascending order of rate of reaction.



The mean scores for all the groups show a slight drop in the post-test and delayed post-test implying that procedural knowledge on order of reactions was retained. The RBL instructional method had 73% and 70% in the post-test and delayed post-test, thus retaining more than the other groups. For question 1.10, the mean of 44% and 42% post-test dropped to 44% and 30%, delayed post-test. There was a disappointing and surprising decline in the knowledge on the order of reactions.

4. Qualitative results

Interviews were conducted to complement the results obtained using the quasi-experiment pre-test-post-test-delayed-post-test design after six months. Interviews with 12 students were conducted using purposive sampling of the students in the lower, middle and upper groups of performance. The responses, that included a correct answer and a scientifically accepted explanation of semi-structured interviews, are presented in Figure 2.

For students in the experimental groups, their responses were mainly in the scientifically acceptable category. Thus, it may be concluded, as obtained from quantitative data, that the use of the box-and-bead analogy (group A) improved retention in chemical kinetics.

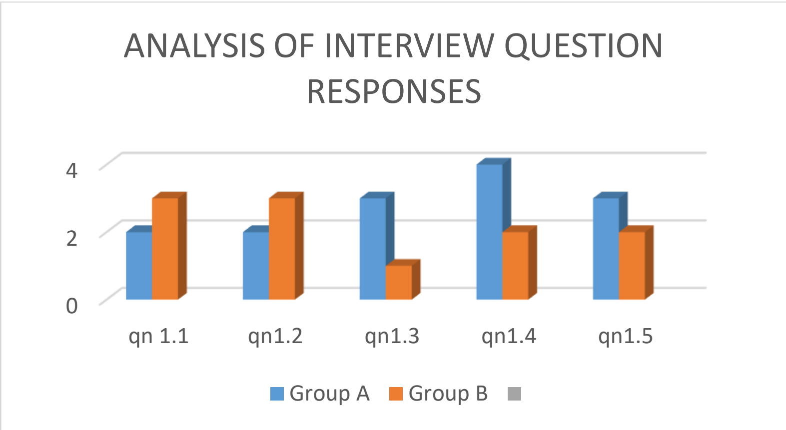


Figure 2: Analysis of interview responses

Excerpts from interviews

Interviews were done to complement the results obtained using the quasi experiment, pre-test-post-test-delayed-post-test design. All the participants were coded with a capital letter (A, B, C) and the subscript representing their number (A_1 student from group A).

> **B_2:** *I had been thinking about reaction orders all along and have looked at different authors. Thinking over and over again and trying to understand conceptually lead me to solve many problems on reactions orders until I was really satisfied.*

B_2 seems to have been motivated by the repeated exposure of retrieving from the long term memory. Retrieving from the long term memory seemed to have helped him to try as many questions from different textbooks. He managed to have a conceptual understanding of reaction orders.

> **B_5:** *Most of the time when I get free time, I will constantly ask myself about chemical kinetics concepts especially temperature dependency. I*

now know about rate constants with less struggle. This question even you ask me after a year I will get it right.

The response of B_5 seems to suggest that RELT enhances intrinsic motivation that will aid in retention through constant retrieval.

> $\mathbf{A_2}$: *The analogy had opened the way I viewed the rate of reaction. Today I know how the rate progresses during the reaction. Through analogies, I managed to understand the Maxwell-Boltzman distribution curve and activation energy. If confronted with a question I will try and go back to the analogy and this has led me to have a fine grasp of the concepts*

> $\mathbf{A_5}$**:** *I never had a correct understanding of activation energy from high school. Working with the analogy made me to have a clear picture about. Each time I get a question the analogy appears in my mind.*

The students from group A relied on concrete analogs to conceptually understand the core concepts in chemical kinetics. Though $\mathbf{A_2}$ admitted that the rate of reaction was vague at first and relied on her mathematical skills relating to the analogy would be used to answer questions.

$\mathbf{B_4}$ was a textbook example of superficially and procedural knowledge which cannot be retained. Although he managed to rank reactions based on their activation energy in the first year, he failed to do so after six months, showing that he lacked a conceptual understanding of potential energy graph versus progression of a reaction.

> A_C: *I have totally forgotten what I did in the first semester. I got this question correct but the ideas just faded. I guess I was working hard in the first semester than now.*

The last interview shows a case of lack of understanding of how chemical kinetics concepts should build up.

5. Discussion

Two instructional approaches were compared on the retention of chemical kinetics concepts but the result showed a declining trend. The findings were similar to those reported by Engelbretcht et al. (2007), wherein it was shown how procedural knowledge was retained the most over three years. RBL had the highest retention, followed by the analogy for questions based on procedural knowledge. Repeated exercises in RBL proved to enhance retention and seemed to improve emotive and intrinsic motivation. This is similar to the findings of Karpicke and Blunt (2011), on RBL, that retrieving knowledge improves the ability to retrieve it again in the future.

Analogy-based instruction had the highest retention on conceptual knowledge of chemical kinetics concepts. The use of the analogy might have impacted students' abilities to visualise the motion and interactions of particles at a molecular level, resulting in the improved germane load. The interviews revealed that students had concrete analogs which they would refer to when answering questions and which served as retrieval cues. The use of familiar and unfamiliar domains in the analogy might have improved the students retention ability.

According to the CLT, concrete analogs could affect germane cognitive loads that lead to the automation of the right schemas. The findings on the use of analogies were similar to those by Didis (2015), that students enjoyed the analogies and it improved the conceptual understanding and retention of quantum theory concepts. The RELT had the least retention and it is concluded that active engagement using the box-bead-analogy leads to better retention of chemical kinetics concepts. The findings of this study are in agreement with several related research studies (Taylor et al., 2016; Shahani & Jenkinson, 2016; D'Ottone & Ochonogor, 2017) that concluded that when students engage with analogies they form concrete analogues that enhances retention.

6. Conclusion

This study aimed at exploring the effects of bead-box-analogy versus RBL on students performance and retention of chemical kinetics concepts. Specific focus was on exploring how the students' conceptual and procedural knowledge understanding improved after the two interventions. The RBL improved performance in the post-test (A= 63.73%, B = 65.34%) and analogy based instruction increased students' retention in the delayed post-test (A= 56.01% and 51.08%). Students retain procedural knowledge better using RBL and conceptual knowledge using the box-bead-analogy.

The present study supports the idea that the RBL and box-and-bead analogy can be used in a college classroom to enhance students' conceptual and procedural knowledge retention of chemical kinetics. Through concrete analogs formed by mappings between the familiar and unfamiliar domains in the box-and-bead analogy, students can master their understanding of basic chemical kinetics concepts. RBL can influence learning in a variety of ways. The study found that it improves emotive and intrinsic motivation. The retrieval of knowledge repeatedly exposes what the students know or do not know and can guide future studying. Overall, the long-term effect of RBL and the box-and-bead analogy requires more investigation, and several questions remain open, such as if the retention is permanent or not.

7. References

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