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Pictorial based learning: Promoting conceptual change in chemical kinetics

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Abstract: This study aimed to examine the effect of pictorial based learning (PcBL) on conceptual change in the topic of chemical kinetics. The four-tier instrument (FTDICK) previously developed was deployed to map conceptual change within chemical kinetics concepts. First-year chemistry students at an Indonesian university formed an experimental and a control group. The experimental group experienced the PcBL approach while the control one experienced direct instruction (DI). The conceptual changes demonstrated by the two groups are classified into four categories, namely complete, partial, false and random. Complete conceptual change (CCC) had the highest occurrence rate among the four categories. However, generalising that PcBL and DI are influential in promoting conceptual change in the field of chemical kinetics may be too ambitious. Therefore, further research is needed to reach that conclusion. The effectiveness of PcBL and DI in promoting conceptual change in this study was almost equal. However, in answering the FTDICK questions, the PcBL students showed a better performance reflecting more sound scientific understanding than DI students did.

Keywords: pictorial representation; direct instruction; four-tier instrument; misconception.

INTRODUCTION

The topic of chemical kinetics is a challenge for many students at both secondary and university levels.[1] Similar to other physical chemistry topics, chemical kinetics demands the integration of conceptual understanding and mathematical ability as well as a correlation with other chemistry topics such as thermodynamics, the theory of molecular kinetics, and other aspects of chemical react-

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ivity. Many studies have revealed that students can successfully acquire knowledge on chemical phenomena following the elaboration of the associated academic content. However, they may still harbour ingrained misconceptions.[2,3] Efforts to promote conceptual changes in situations where students hold misconceptions have been made over the last few decades[4] and they constitute an important part of chemistry teaching. Conceptual change presupposes a restructuring or modification of existing knowledge[2,5–7] such that it becomes a solid piece of scientific knowledge.[2]

Various teaching strategies relevant to the theory of conceptual change can be applied to modify students' conceptions.[2] The implementation of such material related to acids and bases resulted in significant conceptual changes as well as changes in students' attitudes toward chemistry.[4] Another study[8] employed the predict-discuss-explain-observe-discuss-explain (PDEODE) teaching model to promote a conceptual change related to the concept of evaporation.

Another study revealed that the conceptual change on inorganic chemistry was successful in overcoming students' misconceptions related to the topic of the state of matter.[9]

Presenting a visual representation of relevant chemical concepts can be a way of challenging students' thinking processes. Many studies support the theory that a pictorial representation prompts meaningful learning, which helps students master scientific concepts and encourages concept management, concepts acquisition and integration underpinning the cognitive activities.[10] According to the cognitive psychology of instruction, the visualisation approach is a helpful strategy in aiding students to solve multistep tasks.[11] Thus, the use of pictorial representations can be helpful in teaching and learning,[12] including promoting conceptual change. Scientific concepts, including chemical concepts, can be presented, and communicated in many formats, including visual representations (pictures, graphs, photographs, diagrams), tables and mathematical formulae.[12] Depicting chemical concepts within appropriate representations can stimulate students' cognitive development and promote their information processing abilities.[13]

In some studies, the advantage of pictorial representation over verbal-based learning has produced some contradictory results. One study revealed that pictorial and verbal-based instruction had an equal effect on student achievement.[14] Another study reported that verbal-based learning resulted in better student achievement than pictorial-based learning,[15] while the other revealed that students who experienced pictorial-based learning performed better on a pictorial-based test but not on a verbal or multiple-choice one.[16] Arnold and Dwyer[17] found that the implementation of pictorial representations in teaching and learning produced higher student attainment.

Regardless of the small number of contradictory results, the majority of research established those pictorial representations promoted a more productive science learning environment.[17–19] Berg *et al.*[20] revealed that when students had been asked to draw a representational picture after observing a chemical process, they were more likely to produce a reasonable explanation of this process. In another study, macroscopic and sub-microscopic visualisations positively impacted students' discourse.[21] Pictorial representations emphasising the sub-microscopic level have been a tool to improve students' scientific understanding. Students' mastery of chemical concepts is profoundly affected by their ability to interpret abstract concepts.[22] Therefore, the practice in visualising and interpreting these abstract concepts should be incorporated in chemistry teaching.[23]

The PcBL in this study combined pictorial representations, involving the sub-microscopic level, with verbal explanations within the students' pair work class discussions, and written explanations.

EXPERIMENTAL

Research design and instrument

This quasi-experimental study applied the pre-test – post-test non-equivalent group design. It involved two groups of first-year chemistry students (with the age range of 19–21 years old) from an Indonesian university taking a fundamental chemistry course. One group with 23 students was chosen as the experimental group, and the other with 25 students as the control group. The allocation of students in each class within the university is managed by the department. Students are distributed equally in terms of their academic background to ensure homogeneity between classes. This procedure explains the equal prior knowledge between the two groups. Both groups completed a pre-test and post-test with identical questions in the form of the Four-tier diagnostics instrument of chemical kinetics (FTDICK) developed in our previous study.[24] FTDICK is a four-tier assessment tool having answer reason tiers along with attached confidence rating indices (*CRI*) on each tier. The full features of the FTDICK instruments are provided in the Supplementary material to this paper.

The pre-test was carried out simultaneously for both groups, while the post-test was conducted separately. Due to Covid-19 precautions, the post-test for the control group was carried out online using the zoom platform. To ensure that students answered the questions independently, they were requested to turn on the video during the test. The post-test for the experimental group was conducted when the government regulation for delivering all the classes online had not been applied.

PROCEDURE

This study encompassed the following steps.

Pre-test

Within the pre-testing, the students from experimental and control groups completed the FTDICK test, which provided insight into the misconception that students held before they embarked on the chemical kinetics course. Several common misconceptions were uncovered and used to design the pictorial representations to be implemented in chemical kinetics teaching. The most prevalent misconceptions demonstrated by 8.70–45.60 % of students were found in the successive half-lives of first-, second- and zero-order reactions, the effect of concentration on the rate of chemical reaction, and the process of catalysis.

Intervention

Within this study, the experimental group was exposed to PcBL that aimed to address the misconceptions revealed by the pre-test, while the students in the control group learned through DI. The teaching textbooks and duration of teaching for the two groups was the same. The PcBL process was initiated at the start of the kinetics course by presenting images or graphics representing the sub-microscopic processes occurring in various chemical reaction scenarios. The pictorial representations functioned as a cognitive trigger for students. Below is an example of a pictorial trigger presented at the beginning of the session on successive half-lives in chemical reactions.

Fig. 1 provides pictorial representations of successive half-lives for first- and second-order reactions and was used as the trigger at the start of instruction related to the concept of half-lives. In the next step of the procedure, students worked in pairs to extract information

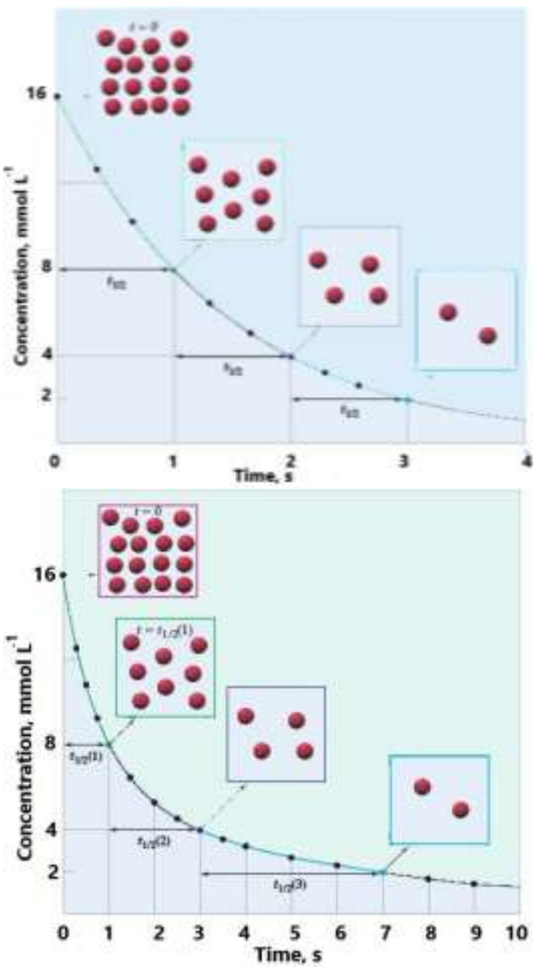

Fig. 1. The pictorial trigger for the concept of successive half-lives of first and second orders.

from the two figures and make comparisons. The information gained from the pictorial representation was discussed in class. This resulted in the conclusion that the time for each half-life is different for first- and second-order reactions. Similar steps were applied in the teaching of other concepts.

Direct instruction (DI) in this study was initiated by a brief review of the previous topic from the last class, followed by teaching on the current topic. Subsequently, students carried out exercises individually or in small groups depending on the tasks' complexity. The teacher then provided constructive feedback and a brief review of concepts covered within that lesson. As explained previously, the textbook for DI group was the same with the textbook for PcBL class. However, the pictorial presentations within the textbook were only used for additional information to support the teacher's explanation.

Post-test

The post-test was employed to explore conceptual changes demonstrated by the students from the experimental and control groups. Eleven questions of the original FTDICK were removed to leave nine questions that focussed on concepts for which students had demonstrated misconceptions. The instrument is provided in Supplementary material.

Data analysis

There are four possible combinations of students' responses to the FTDICK, namely: correct answer correct reason (CACR), correct answer wrong reason (CAWR), wrong answer correct reason (WACR) and wrong answer wrong reason (WAWR). CACR combinations reflect students' scientific understanding of the concepts under investigation. WAWR is the primary indicator of students' misconceptions related to these concepts. Confidence rate index (*CRI*) for each combination is the average of the *CRI* for the A-tier and the R-tier. It reflects the level of students' scientific and unscientific reasoning, as outlined in Table I.

TABLE I. The criteria for classification of students' misconceptions[12]

No.	*CRI* of a WAWR combination	Category
1.	>4.00–5.00	Strong
2.	>2.75–4.00	Moderate
3.	>2.00–2.75	Weak
4.	>1.00–2.00	Lack of knowledge
5.	>0.00–1.00	Guesswork

Students' responses to the pre-test and post-test were graded according to the following procedures. Score 1 was attributed to a CACR combination, while score 0 was attributed to the other combinations (WACR, CAWR and WAWR). The number of students that demonstrated misconception on each question in both the pre-test and post-test, was calculated according to:

$$N = 100\frac{n\text{WAWR}}{Nt} \quad (1)$$

N represents the number of students with misconceptions. *n*WAWR is the number of students providing WAWR combinations in each question. *Nt* is the total number of students participating in this study.

The criteria for classification of students' misconceptions

The strength of students' misconceptions is reflected by students' *CRI* when providing WAWR combinations. The *CRI* values are classified according to the criteria applied by Habiddin.[12] The criteria are presented in Table I.

The difference in performance between PCBL and DI students

The Mann–Whitney U test using SPSS software was employed to reveal the statistical difference in performance of PcBL and DI students on FTDICK. The non-parametric procedure (Mann–Whitney U test) was applied because the Shapiro–Wilk test prerequisite procedure revealed that the collected data were not normally distributed.

RESULTS AND DISCUSSION

Pictorial based learning (PcBL): Addressing students' misconceptions

The misconceptions demonstrated by students on the pre-test were used to develop teaching material for PcBL. As discussed in the method section, PcBL intervention in this study was conducted using a pictorial representation of chemical kinetics' concepts as a trigger for students' cognitive and thinking processes. The PcBL was initiated by giving a pictorial presentation of a specific chemical concept. Following this, students worked in pairs to extract meaningful information from the representation and associated teaching. For example, where more than one image associated with a concept was provided, students were instructed to compare the similarities and differences between the pictorial representations. To overcome the misconception that "the duration of the first- and second half-life is identical (which they are not in any but first-order reactions)", the PcBL was initiated through the pictorial representation presented in Fig. 1.

This misconception was uncovered from students' responses when given a question in which they had to determine the concentration of a reactant in its first- and second half-life. In answering such a question, some students considered that the concentration within the first- and the second half-life is the same. Therefore, Fig. 1 provides a cognitive challenge to students. Fig. 1 was employed to prompt students understand that the time needed for each half-life for a second-order reaction is not a constant as in the case of first-order reaction. This figure is intended to overcome the misconception that the duration of successive half-lives within second-order reaction is identical and draw students' attention to the fact that the constant duration of successive half-lives is only applicable for the first-order reactions. Fig. 2 is the pictorial trigger to overcome the misconception that "a catalyst does not remain chemically unchanged after the reaction is completed." The figure shows that the catalyst, represented by the two red spheres, is not consumed and remain chemically unchanged even though it took part in the reaction, as shown in the central box. The involvement of the catalyst is confirmed by the separation of two red spheres and their recombination.

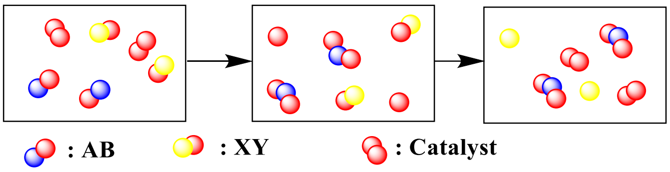

Fig. 2. The Pictorial trigger for the concept of catalyst.

Fig. 3 provides several pictorial clues that the presence of a catalyst increases the reaction rate. The figure is the pictorial trigger to overcome a misconception that "the presence of a catalyst decreases the rate." Fig. 3a depicts the decomposition of HCOOH without the presence of a catalyst. Fig. 3b illustrates the decomposition of HCOOH using the catalyst H^+. The figure shows that the presence of the catalyst lowers the activation energy and leads to a higher reaction rate in comparison to the uncatalysed reaction (Fig. 3a). The figure also indicates another scientific information: the presence of a catalyst provides a different reaction mechanism as depicted by the different steps in the same reaction and multiple transition states in the presence of the catalyst. Some concepts are difficult to display pictorially, and so verbal descriptions had to be used. For example, Table II was used to overcome the belief that "the power of the reactants in the rate law expression for a given chemical reaction is equal to the stoichiometric coefficients in the balanced equation of that reaction." It also demonstrates that the rate law expression cannot be obtained by applying the same procedure as for the equilibrium constant expression. Both of these theories are commonly held misconceptions.[25]

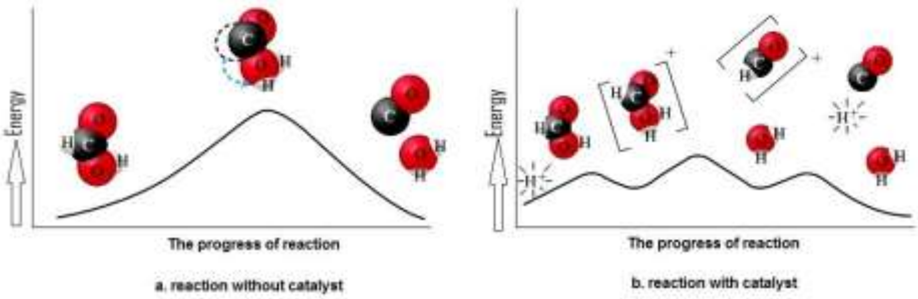

Fig. 3. The Pictorial trigger for the concept of catalyst.

It is likely that the misconception that the rate law expression is obtained from the stoichiometric equation derives from the nature of the examples used during the teaching. If within the examples that the students were given the values of the stoichiometric coefficients and exponents in the rate law expression were identical, this could have led to the conclusion that the latter could be obtained directly from the former. Table II provides examples demonstrating that the rate law is determined experimentally and does not depend on the balanced stoichiometric equation. This table also demonstrates that the rate law expression and the equilibrium-constant expression are different concepts.

TABLE II. The triggering table for the concept of rate law

No.	Chemical equation	Rate law
1.	$CO(g) + NO_2(g) \rightarrow CO_2(g) + NO(g)$	Rate = $kc_{CO}c_{NO2}$
2.	$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$	Rate = kc_{H2O2}
3.	$2NO(g) + Cl_2(g) \rightarrow 2NOCl(g)$	Rate = $kc_{NO2}c_{Cl2}$
4.	$2NH_3(g) \rightarrow N_2(g) + 3H_2(g)$	Rate = $kc_{(NH3)}{}^0 = k$
5.	$Pt(NH_3)_2Cl_2(aq) + H_2O(l) \rightarrow [Pt(NH_3)_2O)Cl]^+(aq) + Cl^-(aq)$	Rate = $kc_{Pt(NH3)2Cl2}$

The figures and table were presented at the beginning of elaboration of the concept of interest. Following this, students worked in pairs to extract valuable pieces of information and relate them to the targeted concept. In the next step, students shared their conclusions with the whole class, and this was followed by a class discussion led by the class teacher.

The process of extracting valuable information from a picture or table, relating the information to the relevant concept and sharing and discussing ideas is expected to trigger students' cognitive processes and finally lead to the conceptual change. These activities are appropriate to the following components of scientific practices formulated by The National Research Council,[26] namely: asking questions, analysing and interpreting data, constructing explanations and designing solutions, engaging in discussion based on evidence, and also obtaining, evaluating and communicating information. These scientific practices were in the focus of science education research over the last decade.[27–29]

Description of conceptual change occurrence rates

Students' conceptual change as a result of the implementation of PcBL and DI approach is determined based on the shift from students' misconceptions demonstrated on the pre-test to a scientific understanding and decrease in the frequency of occurrence of these misconceptions on the post-test. Table III shows the percentages of students holding misconceptions before and after the implementation of the abovementioned teaching approaches. The table presents the complete conceptual change (CCC), partial conceptual change (PCC), false conceptual change (FCC) and random conceptual change (RCC) occurrence rates. CCC means that all the students who previously held misconceptions demonstrated a full scientific understanding given on the post test. PCC means that a only certain portion of the students demonstrated a scientific understanding of given concept on the post-test. A smaller portion of students is still retaining the misconception. FCC means that the number of students demonstrating misconception (MC) on the post-test is even higher compared to the pre-test. RCC means the number of students holding the misconception decreased, but their *CRI* increased and *vice versa*. The comparison of the conceptual change occurrence rates among PcBL and DI students is depicted in Fig. 4.

TABLE III. Conceptual change occurrence rates

Misconception (MC)	Pre-test			Post-test					
				PcBL			DI		
	N %	*CRI*	Category	*N* %	*CRI*	Category	*N* %	*CRI*	Category
MC1: the terminalogy of the first half-life and the second half-life means the same	21.74	3.3	Moderate	5.26	1.5	Lack of knowledge	4.17	1.5	Lack of knowledge
MC2: the reaction rate always increases with a decrease in concentration of reactant	21.74	2.8	Moderate	0	0	Overcome	25	4.5	Strong
MC3: the $t_{1/2}$ value of each successive half-life for the first- and the second-order reactions is identical	26.09	3.1	Moderate	36.84	3.9	Moderate	8.33	4.0	Strong
MC4: the duration of the half-lives of a second-order reaction is constant	23.91	3.6	Moderate	36.84	3.5	Moderate	25	3.0	Moderate
MC5: the power of the reactants in the rate law expression for a given chemical reaction is equal to the stoichiometric coefficients in the balanced equation of that reaction	8.70	2.0	Weak	5.26	1.5	Lack of knowledge	8.33	3.5	Moderate
MC6: the equilibrium-constant expression can be used to derive the rate law expression	45.65	3.3	Moderate	10.52	3.0	Moderate	16.67	3.3	Moderate
MC7: the rate law equation can only be expressed in terms of the rate of disappearance of reactants	26.09	3.3	Moderate	0	0	Overcome	0	0	Overcome
MC8: a catalyst does not remain chemically unchanged after the reaction is completed	17.39	3.1	Moderate	0	0	Overcome	0	0	Overcome
MC9: the presence of a catalyst decreases the reaction rate	13.04	3.8	Moderate	5.26	5.0	Strong	4.17	1.0	Lack of knowledge
MC10: the reaction rate always decreases with time	10.87	2.5	Weak	0	0	Overcome	0	0	Overcome

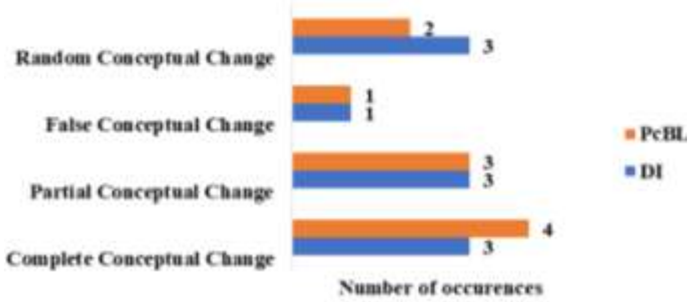

Fig. 4. A comparison of occurrence rates of the four types of conceptual change among students from PcBL and DI groups.

The CCC is the most frequent type of conceptual change demonstrated by PcBL students, whereas the occurrence rates of CCC and PCC are equal within the DI students. The CCC for PcBL students is detected for MC2, MC7, MC8, while for the DI students it occurred in relation to MC10 and MC7, MC8 and MC10. Before the intervention, 21.74 % of PcBL students with a *CRI* of 2.80 held the misconception that the rate always increases with a decrease in concentration (MC2). After the intervention, all PcBL students held a correct scientific understanding regarding this concept. The opposite phenomenon, *i.e.*, FCC, is shown by DI students. The number of students holding the misconception that fell in the "strong" category increased after the intervention. For MC7, MC8 and MC10, both groups demonstrated a CCC. Within MC8, students assumed that "a catalyst does not remain chemically unchanged after the reaction is completed."

After the interventions encompassing Fig. 2, they realised that the catalyst remains chemically unchanged even after it took part in the reaction. The absence of the two connected red spheres representing a catalyst in the central box implies that the catalyst is involved in the reaction. The two connected red spheres in the final box indicated the correct scientific idea to the PcBL students, which is that the catalyst is not consumed in the reaction and that it remains chemically unchanged after it. This study confirmed the work published by Canpolat *et al.*[30] that students taught by a conceptual change approach performed better than those taught by a more traditional approach. The successful conceptual change was also reported in relation to the teaching about acid and base.[4] The improvement in students' understanding after implementing pictorial representations has also been reported in regard to the other chemistry topics.[20,21,31,32]

A PCC was detected in relation to MC1, MC5, and MC6 for PcBL students. A significant decrease in a number of students holding the misconceptions to successive half-lives after experiencing PcBL is strong evidence of conceptual change regarding MC1. Fig. 1 shows that the label $t_{1/2}$ at every point where the concentration of the reactant is half the previous one triggered students' awareness that half-life terminology is applicable every time the concentration is halved. The 5.26 % of students who still held this misconception after the intervention showed a very low *CRI* of 1.5, which falls in the "lack of knowledge" category.

Another significant decrease in the number of students holding the misconception that "used the equilibrium-constant expression to derive the rate law" is revealed in MC6. However, the remaining 10.52 % of students who still held this misconception showed a moderate *CRI*.

Meanwhile, a small decrease in the number of students holding the misconception that "the power of the reactants in the rate law expression for a given chemical reaction is equal to the stoichiometric coefficients in the balanced equation of that reaction" is revealed for MC5. Providing various chemical equations accompanied by their rate law expressions (Table II) did not totally overcome students' misconceptions in regard to this concept. PCC for DI students appears for MC1, MC6 and MC9. As explained before, PCC for MC1 and MC6 also appear for PcBL students. At MC9, a small portion of DI students (4.17 %) still held the misconception that "the presence of a catalyst decreases the rate" but with a very low *CRI* falling in the lack of knowledge category. Some unexpected results regarding FCC are found in relation to MC3 for PcBL students. Even after experiencing PcBL and studying Fig. 1, some students still firmly believed that "the $t_{1/2}$ value of each successive half-life for the first- and the second-order reactions is identical."

Although the *CRI* of those misconceptions remained in the "moderate" category, the number of students holding them increased. This phenomenon confirms the strong familiarity of students with the concept of constant half-life in first-order reactions.[12] Greater emphasis on first-order reactions in chemistry textbooks could be the cause of this misunderstanding.[12] This could also explain the unexpected in finding related to MC4, namely, "the duration of the half-lives of a second-order reaction is constant." This finding is in line with the one published by Tirr *et al*.[15] DI students demonstrated an RCC in this instance. The number of students holding the misconception decreased significantly, but the CRI of those still holding it increased significantly, falling into the "strong category." The RCC is demonstrated by PcBL students regarding MC9 related to the misconception that "the presence of a catalyst decreases the reaction rate."

This misconception is a novel finding. Fig. 3 was used to explore this point with an additional question designed to establish a link between the energies of the different transition states and the relative rates of each reaction. A discussion of the different mechanisms was also instigated. After experiencing PcBL, a complete conceptual change was also demonstrated regard to this concept. The number of students demonstrating this misconception significantly decreased, but the *CRI* of those holding it also increased, falling in the "strong" category.

The fact that PcBL in this study did not completely remediate students' misconception could have a variety of explanations. Firstly, students may not yet be familiar with this teaching approach. Students may need more practice in extracting meaningful information from visual prompts. Secondly, the PcBL approach implemented in this study was provided by the lecturers (who are also the authors). The approach may be enhanced by asking students to draw their pictorial representations of the relevant concepts.[33] Thirdly, the ways in which students initially develop their misconceptions needs to be explored[2] in order to develop better strategies to overcome them. Further studies should consider these shortcomings.

PcBL vs. *DI students' performances*

The results of this study imply that it is not possible to determine which of the two approaches (PcBL and DI) is better in promoting conceptual change. As displayed in Fig. 4, the CCC occurrence rate for PcBL students is higher than that for the DI students. The occurrence rate of PCC and FCC is equal for the two groups. The DI students demonstrate higher RCC occurrence rates compared to the PcBL students. Reflecting on these facts, it seems that PcBL students showed only a slightly better performance than DI students did in terms of the conceptual change. This phenomenon is in line with the work of Wang,[34] who compared inquiry-based teaching and DI.

In terms of students' performance of FTDICK, the Mann Whitney U test revealed that the mean rank of the PcBL students (29.16) is higher than that of the DI students (16.33). Specifically, the U statistic and the asymptotic significance (2-tailed) p-value show that PcBL students' performance in answering FTDICK questions was significantly higher compared to the DI students ($U = 92.000$, $p = 0.001$). This result reinforces the finding that PcBL is effective in achieving CCC for most students who experience it.

CONCLUSION

The implementation of PcBL and DI triggers a conceptual change among students who previously harboured misconceptions in regard to chemical kinetics. Complete conceptual change (CCC) had the highest occurrence rate among the PcBL students, while CCC and PCC occurred with equal frequency among the DI students. FCC also occurred with the same frequency among the students for the two groups, but at the same time, this type of conceptual change was least frequently observed. The existence of PCC, RCC, and even FCC reflects that the implementation of PcBL may not instantly provide a complete conceptual change. To achieve this more practice, particularly in developing students' ability to interpret pictures, graphics and tables, and finally extract valuable information from these representations, is needed. In dealing with pictorial representations, some students face two challenging issues, which are: *i*) difficulty in extracting the relevant information[12,35] and *ii*) errors in transforming the information extracted from the pictorial context into chemical behaviour.[35] Providing more opportunities for students to deal with pictorial representations both in teaching and learning and in the evaluation process will encourage students to become more familiar with such exercise and more confident in their ability to deal with them. A study has shown a link between students' confidence in chemistry with their achievement in chemical kinetics.[36]

Although the results show that the frequency of CCC among the PcBL students is slightly higher in comparison to the DI students, we don't attempt to generalize the conclusions of this study in regard to PcBL for the entire field of chemistry teaching, or even the field of chemical kinetics. However, the conclusions reached within this study may prompt further studies with larger sample sizes and in other chemistry topics and a more readily generalizable inference can be reached in the future. In terms of students' answers to FTDICK questions, the PcBL students demonstrated a better performance in comparison to the DI students. This may infer that the PcBL approach is more potent in improving students' understanding of chemical kinetics than the DI approach.

SUPPLEMENTARY MATERIAL

Additional data and information are available electronically at the pages of journal website: https://www.shd-pub.org.rs/index.php/JSCS/article/view/11740, or from the corresponding author on request.

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ИЗВОД

УЧЕЊЕ ЗАСНОВАНО НА ИЛУСТРАЦИЈАМА: ПРОМОВИСАЊЕ КОНЦЕПТУАЛНЕ ПРОМЕНЕ У ОКВИРУ ТЕМЕ ХЕМИЈСКА КИНЕТИКА

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Ова студија је имала за циљ да испита утицај учења заснованог на илустрацијама (PcBL) на концептуалне промене у оквиру теме Хемијска кинетика. За мапирање концептуалних промена у оквиру концепата хемијске кинетике, коришћен је претходно развијени четворослојни инструмент (FTDICK). Студенти прве године хемије на једном универзитету у Индонезији формирали су експерименталну и контролну групу. Експериментална група је обучавана применом PcBL методе, док је контролна група обучавана применом директне инструкције (DI). Концептуалне промене које су уочене у оквиру ове две групе класификоване су у четири категорије: потпуне, парцијалне, лажне и насумичне. Потпуна концептуална промена (CCC) је имала највећи степен учесталости од четири наведене категорије. Међутим, било би исувише амбициозно генерализовати да су и PcBL и DI ефикасни у поспешивању концептуалних промена у области хемијске кинетике. Да би се извео такав закључак, потребна су додатна истраживања.

Ефикасност PcBL и DI методе у поспешивању концептуалних промена у овој студији била је готово једнака. Међутим, у решавању задатака на FTDICK, студенти PcBL групе су остварили бољи учинак од студената DI групе и тиме показали боље научно разумевање.

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REFERENCES

1. K. Bain, M. H. Towns, *Chem. Educ. Res. Pract.* **17** (2016) 246 (https://doi.org/10.1039/C5RP00176E)
2. G. C. Weaver, in *Chemistsћ Guide to Effective Teaching, Vol. 2,* N. J. Pienta, M. M. Cooper, T. J. Greenbowe, Eds., Pearson Education, Inc., Upper Saddle River, NJ, 2009, p. 35
3. V. Talanquer, *J. Chem. Educ.* **94** (2017) 1805 (https://doi.org/10.1021/acs.jchemed.7b00427)
4. G. Demircioglu, A. Ayas, H. Demircioglu, *Chem. Educ. Res. Pract.* **6** (2005) 36 (https://doi.org/10.1039/B4RP90003K)
5. A.-M. Rusanen, *Sci. Educ.* **23** (2014) 1413 (https://doi.org/10.1007/s11191-013-9656-8)
6. G. J. Posner, K. A. Strike, P. W. Hewson, W. A. Gertzog, *Sci. Educ.* **66** (1982) 211 (https://doi.org/10.1002/sce.3730660207)
7. M. Schneider, X. Vamvakoussi, W. Van Dooren, in *Encyclopedia of the Sciences of Learning*, N.M. Seel, Ed., Springer US, Boston, MA, 2012, p. 735 (https://doi.org/10.1007/978-1-4419-1428-6_352)
8. B. Coştu, A. Ayas, M. Niaz, *Chem. Educ. Res. Pract.* **11** (2010) 5 (https://doi.org/10.1039/C001041N)
9. R. S. Rohmah, F. Fariati, S. Ibnu, in *Proceedings of The 3rd International Conference on Mathematics And Science Education (ICOMSE)*, (2019), Malang, Indonesia, AIP Conf. Proc., American Institute of Physics, Melville, New York, 2020, p. 20020 (https://doi.org/10.1063/5.0000492)
10. K. M. Edens, E. F. Potter, *Stud. Art Educ.* **42** (2001) 214 (https://doi.org/10.2307/1321038)
11. D. C. Orlich, R. J. Harder, R. C. Callahan, M. S. Trevisan, A. H. Brown, *Teaching Strategies: A Guide to Effective Instruction*, 9th ed,. Wadsworth Publishing, Boston, MA, 2010
12. Habiddin, *PhD Thesis*, University of Reading, 2018
13. T. Gegios, K. Salta, S. Koinis, *Chem. Educ. Res. Pract.* **18** (2017) 151 (https://doi.org/10.1039/C6RP00192K)
14. J. Snowman, D. J. Cunningham, *J. Educ. Psychol.* **67** (1975) 307 (https://doi.org/10.1037/h0076934)
15. W. C. Tirr, L. Manelis, K. L. Leicht, *J. Read. Behav.* **11** (1979) 99 (https://doi.org/10.1080/10862967909547313)
16. K. L. Alesandrini, J. W. Rigney, *J. Res. Sci. Teach.* **18** (1981) 465 (https://doi.org/10.1002/tea.3660180509)
17. T. C. Arnold, F. M. Dwyer, *Percept. Mot. Skills* **40** (1975) 369 (https://doi.org/10.2466/pms.1975.40.2.369)
18. J. Rigney, K. Lutz, *J. Educ. Psychol.* **68** (1976) 305 (https://doi.org/10.1037/0022-0663.68.3.305)
19. W. G. Holliday, *J. Res. Sci. Teach.* **12** (1975) 77 (https://doi.org/10.1002/tea.3660120111)

20. A. Berg, D. Orraryd, A. J. Pettersson, M. Hultén, *Chem. Educ. Res. Pract.* **20** (2019) 710 (https://doi.org/10.1039/C8RP00288F)
21. V. Hunter, I. Hawkins, A. J. Phelps, *Chem. Educ. Res. Pract.* **20** (2019) 851 (https://doi.org/10.1039/C9RP00064J)
22. R.B. Kozma, J. Russell, *J. Res. Sci. Teach.* **34** (1997) 949 (https://doi.org/10.1002/(SICI)1098-2736(199711)34:9<949::AID-TEA7>3.0.CO;2-U)
23. B. Bucat, M. Mocerino, in *Multiple Representations in Chemical Education*, J.K. Gilbert, D.F. Treagust, Eds., Springer Netherlands, Dordrecht, 2009, pp. 11
24. H. Habiddin, E. M. Page, *Indones. J. Chem.* **19** (2019) 720 (https://doi.org/10.22146/ijc.39218)
25. T. Turányi, Z. Tóth, *Chem. Educ. Res. Pract.* **14** (2013) 105 (https://doi.org/https://doi.org/10.1039/C2RP20015E)
26. N. R. Council, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, The National Academies Press, Washington DC, 2012
27. M. Evagorou, S. Erduran, T. Mäntylä, *Int. J. STEM Educ.* **2** (2015) 11 (https://doi.org/10.1186/s40594-015-0024-x)
28. J. Osborne, *J. Sci. Teacher Educ.* **25** (2014) 177 (https://doi.org/10.1007/s10972-014-9384-1)
29. R. S. Schwartz, N. G. Lederman, F. Abd-el-Khalick, *Sci. Educ.* **96** (2012) 685 (https://doi.org/10.1002/sce.21013)
30. N. Canpolat, T. Pınarbaşı, S. Bayrakçeken, O. Geban, *Res. Sci. Technol. Educ.* **24** (2006) 217 (https://doi.org/10.1080/02635140600811619)
31. M. Baptista, I. Martins, T. Conceição, P. Reis, *Chem. Educ. Res. Pract.* **20** (2019) 760 (https://doi.org/10.1039/C9RP00018F)
32. G. Eymur, Ö. Geban, *Int. J. Sci. Math. Educ.* **15** (2017) 853 (https://doi.org/10.1007/s10763-016-9716-z)
33. V. M. Williamson, T. J. Jose, in *Chemists' Guide to Effective Teaching, Vol. 2*, N. J. Pienta, M.M. Cooper and T. J. Greenbowe, Eds., Pearson Education, Inc., Upper Saddle River, NJ, 2009, p. 71
34. J. Wang, *Int. J. Sci. Math. Educ.* **18** (2020) 1063 (https://doi.org/10.1007/s10763-019-10010-7)
35. H. Habiddin, E. M. Page, *Int. J. Sci. Math. Educ.* **19** (2021) 65 (https://doi.org/10.1007/s10763-019-10037-w)
36. H. Habiddin, E. M. Page, H. Herunata, O. Sulistina, W. Winartiasih, M. Muarifin, M. Maysara, in *Proceedings of The 3rd International Conference on Mathematics and Science Education (*ICOMSE*)*, (2019), Malang, Indonesia, AIP Conf. Proc., American Institute of Physics, Melville, New York, 2020, p. 20006 (https://doi.org/10.1063/5.0000502).