***JKPK (JURNAL KIMIA DAN PENDIDIKAN KIMIA)**, Vol. 10, No. 1, 2025* *pp. 220-233*
Chemistry Education Study Program, Universitas Sebelas Maret *ISSN 2503-4146*
https://jurnal.uns.ac.id/jkpk *ISSN 2503-4154 (online)*

A Portable Laboratory Kit for Student Self-Learning on Factors That Affect Reactions

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ARTICLE INFO

Keywords:
Laboratory kit;
Intertextual;
POE;
Concept mastery;
reaction rates.

Article History:
Received: 2024-02-09
Accepted: 2025-03-15
Published: 2025-04-30
doi:10.20961/jkpk.v10i1.84495

ABSTRACT

In chemistry practicums, students can enhance their scientific thinking skills and develop scientific attitudes. However, in some underprivileged schools, particularly during the COVID-19 pandemic, practicum activities were restricted due to the unavailability of laboratory tools and materials. To address this issue, a portable laboratory kit was developed to support practical learning experiences. This study aims to develop a portable laboratory tool model, integrating the Predict-Observe-Explain (POE) approach, to improve students' learning outcomes on reaction rates. This research employs a mixed-methods approach with an embedded experimental model, utilizing a one-group pretest-posttest design. The portable laboratory kit includes hands-on tools and materials, student worksheets, and teacher guides aligned with POE learning syntax. Three experts conducted validation and implementation involving 24 high school students. A novelty of this study lies in the practical worksheet design, which follows the POE learning syntax and fosters intertextual relationships across macroscopic, submicroscopic, and symbolic representations. The findings reveal a significant difference between pretest and posttest scores regarding students' understanding of factors affecting reaction rates. Specifically, the number of students who demonstrated complete understanding after the intervention was: nine for the effect of structure on reaction rate, 13 for the effect of ionization energy on reaction rate, and 20 for the effect of surface area on reaction rate. Regarding catalysts, 15 students fully understood the effect of a homogeneous catalyst, and 18 students understood the effect of a heterogeneous catalyst. Interviews with teachers and students further indicated that students found the approach novel, motivating them to engage more deeply. Additionally, many students expressed feeling particularly challenged during the prediction stage of the POE learning process.

Corresponding Author: tuszie@upi.edu
How to cite: T. Widhiyanti, J. A. Fatihah, S. Mulyani, and Wiji, "Portable Laboratory Kit for Students ' Learning of Factors That Affect Reaction," *Jurnal Kimia dan Pendidikan Kimia (JKPK)*, vol. 10, no. 1, pp. 220–233, 2025. [Online]. Available: http://dx.doi.org/10.20961/jkpk.v10i1.84495.

INTRODUCTION

Chemistry is concerned with processes such as the intra-action among atoms, molecules, and ions, and the solubility of mixtures in solvents—processes that are not immediately perceptible at the human experience level. However, the public tends to understand chemistry by giving meaning to the invisible and untouchable and providing images of molecular phenomena [1]. The reaction rate is one of the most difficult chemistry concepts for students. This difficulty stems from the abstract nature of reaction rates, which involve the dimension of time in relation to the level molar, molecular and electrical based on Jensen's scheme [2]. Teaching chemistry based on three levels of representations can promote students' holistic understanding [3]–[5]. The three tiers of representation are macroscopic, microscopic, and symbolic levels [6]. The macroscopic level refers to the observable phenomena and concrete substances; the microscopic level is used when explaining submicroscopic interactions; and the symbolic level represents chemical processes using chemical symbols, mathematical equations, and visual models [6], [7]. Speculative representations, including drawings and symbolic diagrams, also contribute to students' understanding of chemical phenomena [7].

The representational function of each level plays an important role in enhancing comprehension and explaining chemical concepts [7]. Furthermore, effective learning requires connecting the three levels of representation with students' previous knowledge and experiences, which serve as valuable cognitive resources. The interrelatedness among chemical representations and students' prior experiences is called intertextuality in chemistry learning. During instruction, fostering intertextual relations can serve as a strategy to facilitate comprehensive concept construction [5].

In practice, teachers often struggle to teach and connect the three levels of representation accurately. Studies indicate that approximately 80% of chemistry teachers cannot effectively transform between different types of representations within the context of chemical substances [8]. Consequently, traditional lecturing persists, often without laboratory experiences, and students are left to memorize concepts without meaningful understanding.

Understanding the three levels of representation is crucial for mastering chemistry and avoiding misconceptions. Misunderstandings arising from representational gaps are categorized as science-construct discrepancies [9].

This issue is further supported by research findings showing that many students cannot describe phenomena across macroscopic, microscopic, and symbolic levels, often relying on rote memorization without grasping the underlying meaning [1].

Several studies have identified persistent difficulties and misconceptions among students regarding reaction rates [10]–[14]. Common misconceptions include the belief that reactants forming an activated complex have higher energy than the activated complex itself [13]–[15], and that reactants with larger surface areas slow down rather than accelerate reactions [12], [15], [16].

The role of practical work in developing conceptual understanding in chemistry cannot be overlooked. In comprehending the factors influencing reaction rates, the curriculum requires students to experience the practical aspects, providing them with a concrete glimpse into the concept. Practical work is recognized as essential in science learning [17].

However, implementing practical activities remains a challenge, particularly in rural schools where materials are limited, a situation that was exacerbated by the COVID-19 pandemic [18]. Although micro-scale equipment can substitute for experimental experience, it is costly and typically targets narrow objectives [18].

Concerns about students' declining scientific process skills were raised during the post-pandemic period. Between 2020 and 2024, reports indicated that approximately 55% of secondary schools in Indonesia lacked laboratory facilities. Thus, there is a pressing need for effective, low-cost, and widely accessible practical resources. A practicum kit, a flexible learning tool, has been shown to support science learning in environments with limited laboratory access, both inside and outside of schools, by stimulating creativity, enhancing conceptual understanding, and fostering positive scientific habits [18]. Positive feedback has also been reported regarding using laboratory kits in chemistry education [19], [24].

In contrast, remote practical activities that do not involve hands-on experiences fail to expose students to direct applications, thereby limiting opportunities to develop higher-order cognitive skills such as critical thinking, scientific reasoning, and the ability to relate new information to prior knowledge [20]. As defined in previous studies [18], a laboratory kit includes components for recording observations and conducting post-laboratory activities. To maximize learning outcomes, laboratory kits should be accompanied by student worksheets that integrate the three levels of chemical representation. The presence of learning media, such as practicum kits and worksheets, is essential for facilitating student understanding of chemistry concepts [21].

To enable a realisation of a practice kit of that kind, a learning set is needed which contains three stages of representation development and can support the student's process abilities. Several proposed solutions from some literature for handling the lack of mastery of the student concept of the concept of factors that influence the reaction rate, such as through the model cooperative learning and the learning method VAK (visualization, auditory, kinesthetic) [22], inquiry guided instruction but in the process of developing the concept student does not use guiding questions in a worksheet [23], and learning predict-observe-explain (POE) through practicum subjects and provide about training at the stage of commercial explanation. Still, the prediction stage did not give the phenomenon and the process of developing the concept of students through reading a book and discussion [24]. Some solutions came close, but not yet with the three levels of chemical representation and the association.

Hence, studies have recommended researching different areas of science [25]. The rationale for this is that POE is based on the constructivist view of learning that states plainly that any attempt to predict, observe, or explain anything we have observed will help us construct a well-formed understanding about that item.

Construct of knowledge [26]. As a result, the kit employed an intertext-based POE learning model to enhance the mastery of students' concepts in carrying out this solution.

METHODS

1. Research Design

The study employed mixed methods of embedded experimental design and one-group pretest-posttest design. Mixed methods define a research methodology that provides philosophical assumptions of collecting and analysing data simultaneously, and combines quantitative and qualitative approaches in the study process through several phases [27]. Embedded experimental models use qualitative data in experimental designs [27]. The design of a mixed-method embedded experimental model is based on the fact that one case occurs before implementation, where qualitative data is obtained to develop laboratory kits as the Portable Intertextual-Based Learning Model (PIBLM), implementing the POE model. At the same time, another is conducted simultaneously during the implementation process, involving both qualitative and quantitative observation of learning design and student skills. After the introduction, data is gathered more quantitatively as a pretest. Interviews were also performed to determine students' and teachers' reactions to the laboratory kit.

2. Portable Lab Kit Development

Science learning is not complete without lab-scale practicals. School-based learning also faces challenges because some practicum schools in rural areas have inadequate practicum equipment and materials. The COVID-19 pandemic has worsened the situation [18]. Microequipment might serve as an alternative source of experimental work, but this is costly and is often designed for teaching very narrow amounts of content [18]. This recombinant practice kit is versatile as it can be used in schools with limited laboratory facilities, or outside the classroom and school. Furthermore, the practicum kit is designed intertextually with POE to promote ease of use by educators, since it also contains a worksheet and a guide for educators.

This practicum manual includes a Material Safety Data Sheet (MSDS) and detailed practicum procedures.

Three expert lecturers in chemistry education tested the optimized practicum kit for feasibility. The feasibility test covered five aspects: the practicum kit's relation to the material, educational value, durability of tools, safety, and the quality of the kit box. Validation results showed that the intertextual-based practical kit with POE was good for reaction rate learning.

Further investigations in different areas of science have been recommended [25]. The POE model is based on constructivist learning theory, which posits that attempts to predict, observe, and explain anything observed will develop a good cognitive structure [26]. Thus, to apply the POE learning model, this practicum kit uses a text-based intertextual POE learning model to enhance the mastery of students' concepts.

3. Participants and Setting

The subjects of this study were 24 grade XI students of a Senior High School in Bandung City, Indonesia. Qualitative data were obtained using practicum kit eligibility test instruments, observation sheets, and interview guidelines, and quantitative data were obtained by collecting the data using research instruments (pretest and posttest) on student conceptual mastery with laboratory kits. The posttest of the student was also qualitatively analyzed using their outcome to identify the profile of individual student mental models relative to the influence of substances on reaction rate.

4. Data Collection Methods

Data on feasibility for the practicum kit as a learning medium was collected through expert lecturers of the practicum guide (expert judgment). Interviews were conducted with several students and chemistry teachers randomly chosen pre- and post-implementation of the learning design. Student performance pretest and posttest were utilized to measure student comprehension.

5. Qualitative Data Analysis

Results from interviews and video and/or audio recordings were analyzed, meaningful statements were quoted and, according to research objectives, the descriptions were obtained in a narrative form to present the qualitative data analysis results of this research, which are divided into two, i.e., (a) data analysis of results of a feasibility test of a practical kit, interviews and (b) data analysis of posttest results on the mastery of the concept of influence of the condition of reactants and catalysts on the reaction rate.

6. Quantitative Data Analysis

The present quantitative data analysis is employed to measure the effect of applying the IBSD based on the POE model to the material of the effect of reactant and catalyst conditions on reaction rates on the concept mastery. N-Gain test [28] can determine the general profile of an increase in learning outcome scores between pretest and posttest scores after applying the method. Further investigations on different scientific problems have been proposed [25]. The reason for this is that the POE model is based on constructivist learning theory, which states that if one attempts to predict what is going to happen, observe it, and then try to explain what has been observed, one will eventually end up with a well-shaped cognitive structure [26]. Thus, to adopt this practice kit, a POE intertext learning model was employed to enhance student concept mastery.

RESULTS AND DISCUSSION

1. Laboratory Kit

It provides flexibility – its features make it usable in schools with limited lab facilities and for use outside the classroom and school meetings. Students can implement this lab kit as instructed on the worksheet supplied with the lab. The worksheet includes the lab recipe and teaching questions to assist students with answering questions on how reaction rates work together. The ACHS-designed practicum kits will be intertextually-based with POE so teachers can use it seamlessly, it includes not only physical tools and equipment but sheet for the students worksheet for some of the activities, tools and equipment for teaching the concept, the effect of ionization energy, surface area, molecular structure, homogeneous and heterogeneous catalysts on reaction rates among others, as well as teacher casebook. The guide in this lab kit already has an MSDS and your practice set up.

Five of these experiments are given as examples in this kit, but they are not all intended for students and teachers to try in the classroom, for safety reasons. These five experiments are: reaction differences between alkaline metals and water, reaction of calcareous stone with chloric acid solution, phosphorus reaction with air, the reaction of hydrogen peroxide with a catalyst of potassium iodide and manganese (IV) oxide. The most difficult practicum for students is the catalysis effect on reaction rate practicum. This experiment examines the strength of the flame in a series of experiments to determine which experiment will release a larger quantity of oxygen gas. This lab kit can be utilized to examine the nature of the reactant on the rate of reaction, the concentration on the rate of reaction, and the catalyst on the reaction rate. The temperature was not introduced in the first practical kit design, so we did not include a thermometer. However, to customize this to teach the effect of temperature on the rates of reactions, one would need to add a thermometer.

Before trying it with students, the laboratory kit was proven valid by an expert committee. The experimental optimization was proved by studying the effect of the surface on reaction rate and of homogeneous and heterogeneous catalysts on reaction rates. The experts have indicated that this intertext-based laboratory kit has good content, durability of the tool, and user friendliness (in the case of safety, the ease of picking up or storing the kit). Three levels of representation, such as macroscopic, symbolic, and sub-microscopic, can be taken by students in learning through this laboratory kit. Students will receive their macroscopic via self-experiment and a video of the experiment (YouTube link on student handout). Symbolic and indirectly sub-microscopic, on the other hand, are soluble for students, with the help of probing questions provided in the student worksheet.

Optimization of the design of the laboratory kit is carried out, considering the amount of chemical reagents required, the amount of reagents supplied to the user, the size and type of suitable equipment, safety, and disposal of chemical wastes [18]. The things the experiment does not do directly are done by chemical reactions on video (which are referenced in the worksheet).

Components provided in an intertextually based POE laboratory kit for concept-based practicums, such as tools and materials for conducting experiments (such as three Erlenmeyer flasks, two reaction tubes, 50 mL of 2 M HCl solution, etc.), a manual kit, a teacher manual, a material safety data sheet, and a student worksheet. These items are then placed in a kit (40 cm (L) × 24 cm (W) × 15 cm (H)) as seen in Figure 1.

Figure 1. Intertext-based laboratory kit with POE model

2. Implementation of Intertext-based Laboratory Kit in POE Learning

POE-type phase of learning materials that are used as a tool for the Predict-Observe-Explain (POE) are used as a lab kit in student learning with intertext concept factors that influence reaction speeds. As defined in [29], POE is prediction, observation, and explanation. In general, a textbook (Material-Practicum Kit) was well implemented with POE, based on intertext, thereby relating students' experience, knowledge level of students, macroscopic, submicroscopic, and symbolic levels to the learning process. The learning is executed at two meetings, corresponding to two different concepts. Accordingly, pre-test and post-test are applied per meeting based on the studied concepts. The learning process with this practice kit is student-centered, where they study in groups completely autonomously with teacher instruction, also written in the student sheet.

Briefly, learning consists of a learner reading about a reaction involving a phenomenon, given some treatment, and predicting the reaction rate. They put this prediction to the test as they practice using the tools and materials in the kit. Students may experience cognitive dissonance if the predicted model results do not match the observed practical results. To account for what had happened, students were encouraged to talk in groups about answering pointed questions until a solution was found.

3. Impact of Laboratory Kit Usage

Mastery of the mastery concept of concepts after using the intertextual laboratory kit with POE in the concept of the nature of reactant and catalyst against the rate of reaction. The mastery of the poison account concept and the catalyst's electronic structure (reactant) against the speed of the reaction is captured using a double-tier item. On the first stage, the question was correlated to the macroscopic level, and at the second level, it was correlated with the submicroscopic level. Upon implementation of the nature of the reactant's effect on reaction rates, the average student pre-test score was 25/100. This demonstrates that before their implementation, students' mastery of the concept was virtually nil because they were not taught it in school. The questions on the effect of molecular structure and ionization energy on the rate of the reaction were answered wrong by almost all students except the surface area which some students answered right for the first-degree question about their effect on the reaction rate, and the students answered what, maybe the answer is not right for this effect. Second-level questions were not answered by all students either. Therefore, the right treatment is required to compensate for the student's lack of understanding of the effect of reaction state on reaction rate. When the intertext with POE as a learning design is used in the effect of reactant nature on reaction rates topic, it can increase the post-test score of students, as evidenced by the average students' post-test score: 76.4 out of 100.

For an overall characterization of the learning score increase before and after laboratory kit usage, the normality test gain or n-gain is the parameter to be used [28]—the quantitative measurement against pretest and post-test scores calculates the n-gain of each student category. In summary, the influence of using intertext-based laboratory kits with POE on the effect of the nature of reactants on reaction rates is shown in Table 1. Figure 2 also reveals an enhanced understanding of how reaction conditions affect the reaction rate.

Table 1. Number of Students and N-gain Category on the Concept of the Effect of Nature of the Reactant on Reaction Rate

Number of Students	N-gain Category
9	High
15	Medium

All the participants indicated an enhanced mastery of the concept of the effect of the nature of the reactant on reaction rate (Fig. 2). It is also consistent with findings reported in [30], that intertextual learning based on the POE model can improve students' mastery of the concepts and skills related to the process of science.

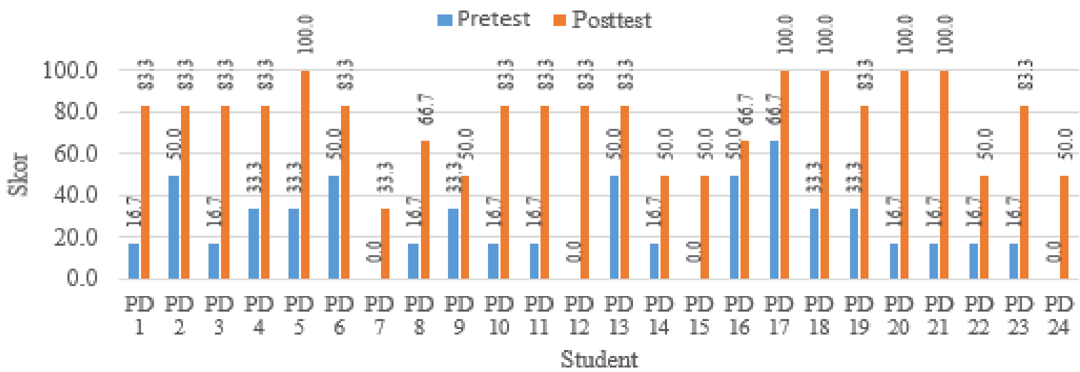

Figure 2. Graph of Pretest-Posttest Improvement on the Effect of Nature of the Reactant on the Reaction Rate of each Student

From the above analysis, a non-parametric statistical test was conducted, i.e., the Wilcoxon test (because the data is abnormally distributed), and the result indicated that there were differences in students' concept mastery skills before and after the implementation of learning with the POE model using the laboratory kit based on intertext. The difference can be observed from the N-gain test result, demonstrating increased pre-test to post-test scores. Moreover, results of the post-test analysis further revealed that in the concepts of the molecular structure effect, ionization energy effect, and surface area effect on reaction rates, in sequence, 9, 13, and 20 students already had a full grasp. The others still understand or do not yet understand. Students mostly struggle at the sub-microscopic level with the influence of molecular structure and ionization energy on reaction rates. Responses to the concept of the effect of surface area on the rate of reactions are also incorrect by some students, due to their still poor grasp of the concept and a lack of understanding of the definition of surface area.

The mean score for the student pre-test on the concept of the effect of a catalyst on the reaction rate obtained from the analysis was 43.8%. Students presumably already knew that a faster reaction would occur in some of the phenomena, as inferred from the pre-test. However, fewer students could answer the level two questions for each item. Following the intertextual-based learning with POE on the effect of catalysts on reaction rates in the second meeting, the mean post-test score of students was 81.25 out of 100. Overall, the description of the effect of using intertextual-based learning design with POE on the effect of catalysts on reaction rates can be seen in Table 2.

Table 2. Number of Students and N-gain Status on the Matter of the Influence of Catalyst on Reaction

Number of Students	**N-gain Category**
9	High
14	Medium
1	Low

Figure 3 indicates that nine students passed the post-test. This pretest-posttest item is used to assess students' understanding of factors affecting the reaction rate, and is given on the same day. Pretest is administered before the learning condition, and post-test is administered after the learning process using the practicum kit. The rise in students' post-test scores is observed after they learned using the intertextual-based POE model through the practicum kit. Thus, this post-test score represents the level of student comprehension; the larger the score, the better the students' comprehension is approaching completeness. This is consistent with the findings reported in [31] that kits learning can contribute to better comprehension by students.

Students with poor N-gain scores are presented in Table 2. Students' N-gain score for P4DS model N-gain range, frequency (f), and percentage (%): PD7f 4 (26.6%), 5f 13 (86.6%), International Journal of Information and Education Technology, Vol. As student 7 learns, he can fill in the questions on the worksheet, but may not draw conclusions from evidence. It is indicative that students have an incomplete understanding of the term that the effect of catalysts on reaction rates is not zero.

When the student scans and records these answers in the workbook, the student will have failed to link the answers from one question to another to conclude.

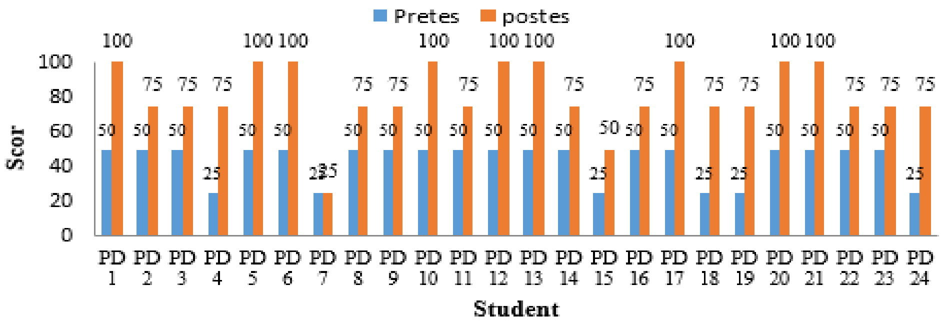

Figure 3. Graph of Pre-test Post-test Improvement on the Effect of Catalyst on the Reaction Rate of each Student

Wilcoxon's test results reveal significant differences in the mastery of the concept of students before and after using the intertextually based laboratory kits for the reaction rate effect of the catalyst. The difference can be observed from the N-gain test score, which increases from pre-test to post-test. This is also consistent with the findings reported in [32], where the kit test indicated that 91% understood the chemical reactions that happened. Though informing students that their ideas are wrong, as traditional methods do, is ineffective for students to develop an understanding of scientific knowledge [11]. Yet, teaching methods designed to engage students in learning are meaningful and motivating.

During the learning process, the students carry out all learning activities based on the instructions on the worksheet, which is a part of the laboratory kit. It implies that this approach could be followed as home teaching or in schools that have not yet been able to use the laboratories. The findings of this analysis of student achievement are consistent with those reported in [33], stating that learning using laboratory kits can significantly enhance students' learning motivation, activities, and cognitive outcomes.

4. Student and Teacher Responses about Implementation of Laboratory Kit

Interviews were carried out before and after the application of the model to determine the reactions of teachers and students toward intertextual laboratory kits with POE models on the concept of factors influencing reaction rates. According to the interview, one meeting for the study of the practice of one-factor rate was considered too long since, for the school, there are still many other chemical materials that should be taught. Interviews were conducted with six chemistry teachers in the researched school, and students were selected randomly. Before the learning, the students could not practice chemistry (lab) since the laboratory could not be used because of being renovated, and COVID-19 affected access to the laboratories, so it was not possible to use the lab. Some students, as confirmed by their teacher, still depended on teacher-centered learning.

After the implementation, the interview results revealed that the students were motivated to learn when learning with the laboratory kit. This is consistent with the findings reported in [34], that practicums in chemistry can improve student motivation, interest, and achievement, providing a foundation to build active chemistry learning. However, students can still struggle at the prediction stage, as they must predict information based on prior knowledge and personal experience. Furthermore, the chemistry teachers' interview results after the implementation also showed a positive response; however, it was noted that improvements should be made related to the implementation of learning, suggesting that two meetings should be conducted for the factors affecting reaction rates topic, since in the 2013 curriculum, there are still many other chemical concepts to be achieved within one semester.

CONCLUSION

Experiments are very necessary in teaching and learning chemistry; We need experiments to present the macroscopic level to students, and a bridge also needs to link the macroscopic level observed with symbolic, using the submicroscopic level so that the students' understanding becomes complete. However, this hands-on experience may be challenging for schools with inadequate lab resources. A POE model portable intertextual-based laboratory kit equipped with three levels of chemical representation, compiled by POE model components, can improve student achievement on the factors affecting the reaction rates and student learning motivation. The developed practical kit has been content validated by experts based on five content validity aspects: the relevance of the practical kit to the topic, learning utility, tool safety, safety for students, and simplicity of its box. The calculation from the study showed differences before and after using the practical kit in mastering the concept of factors that affect the reaction rate. It is suggested in this study that learning tools with hands-on kits need to be developed for other chemical concepts..

ACKNOWLEDGE

We express our deepest gratitude to the supervisors, validator, and colleagues for their assistance, the participants, and the intertextual research group, Department of Chemistry Education, Indonesia University of Education, for the financial support.

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