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# Four-Tier Diagnostic Test on Chemical Kinetics Concepts for Undergraduate Students

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**ABSTRACT**
This study aims to produce a four-tier diagnostic test instrument on concepts in Chemical Kinetics where students experience misconceptions through the four-tier misconception diagnostic test. The test was developed based on several concepts: reaction rate, activated complex, reaction rate law, reaction order, rate constant (k), activation energy, catalyst, integral rate equation, half-life, reaction mechanism, overall reaction, elementary reaction, and Intermediate. This research developed a four-tier test diagnostic test instrument for concepts in Chemical Kinetics according to which consists of 6 stages (clearly identify the outcome, determine to measure the outcome achievement, determine the specific details, determine when to administer the instrument, design the instrument, and pilot test the revise the instruments). The instrument used to gain the validity data was a validation sheet given to the rater. The source of the data for this research is the expert appraiser from rater. There were 4 raters who gave a score for each question item in the four-tier diagnostic test. This development of the four-tier diagnostic test instrument was analyzed for theoretical validity in terms of content and construct (language and graphics) validity. The findings present theoretical valid for 19 questions of four-tier diagnostic test developed on kinetics concepts in content and construct a point of view.

***Keywords:*** *Four-tier diagnostic test; Chemical kinetics; Concept; Validity; Misconception.*

## 1. INTRODUCTION

Chemistry learners must be able to understand chemical phenomena correctly. The correct understanding according to the agreement of the chemists will make it easier for learners to learn other related concepts. Whether or not this understanding is correct is based on the understanding of the agreement with the chemists in their fields for each chemical concept. The incompatibility of understanding concepts with concepts that have been agreed upon by chemists will lead to misconceptions or alternative understandings of concepts. Some misconceptions are cases of generalization by learners that are too narrow because these misconceptions learners fail to include relevant objects or events [1]. The misconceptions in learners' thinking are caused by learners' preconceptions or initial concepts, associative and humanistic thinking, incomplete or wrong reasoning and intuition, stages of learners' cognitive development, and learners' knowledge [2]. Since learners construct or construct their own concepts, their constructions are different from those held and tried to be presented during learning [3]. It can be said if learners can explain what and how a conception differs from others and can apply to understand concepts describe examples of the conception and apply the conception to new situations [4]. If the prejudice is accurate it will increase the ease of learning new information correctly, but if this prejudice is not in accordance with what is agreed upon by the experts it will result in a misconception [5].

A common misconception that often occurs in society is that it is possible to live without chemicals and it would be quite an experiment to attempt this [6]. Misconceptions on chemical concepts also occur both at the high school and college levels. Several studies have shown that pre-service teacher experience misconceptions, among others, in the material and the nature of the material, as well as general chemistry that occurs in Turkey [7] [8]. In Poland, researchers found that there are still misconceptions about the matter of salt hydrolysis occurring in high school students [9]. Misconceptions occur in learners in Indonesia, one of which is in the material of orbitals and quantum numbers [10]. In Slovenia, learners' misconceptions regarding sub-microscopic and symbolic levels in chemistry [11]. Misconceptions can be happened when learner process

 

wrong concept categorization or in other words that misconception occur as a result of ontological errors. [12]. Misconception is difficult to correct because misconceptions are stable and permanent [13] [14]. Alternative conceptions (misconception) can cause the learners difficult to understand or believe ideas (usually new ideas), even if they are understood [4] [15]. Misconception becomes an obstacle in understanding scientific perspectives so that it is important to consider how to uncover misconceptions [13]. Concepts related to chemical kinetics are prerequisite concepts in studying related materials for example, chemical equilibrium.

Diagnosing misconceptions that occur in learners must be done so that educators can correct these misconceptions and make it easier for learners to learn related concepts. Several studies on developing misconceptions diagnostic tests were carried out such as the Development of Open Ended Question [16], Development and Validation of FTDICK [17]. In the four-tier test, wrong reasoning on multiple-level multiple-choice test items with the addition of confidence level in the four-tier test provides an opportunity to assess misconceptions in the nature and strength point of view [14] and a four-tier diagnostic test can uncover the misconception in much more detail [18]. Four-tier test answers can be used to differentiate the understood concepts, not understood concepts, and misconceptions supported by reasons and confidence levels [18]. In this research, the authors develop a four-tier diagnostic test in labels, definitions, attributes, and examples of Chemical Kinetics concepts.

## 2. METHODS

### *2.1 Design*

This study was conducted based on Barkman (2002) instrument developing design consists of 6 stages: a. Clearly identify the outcome, b. Determine the achievement measurement of outcome. c. Determine the specific details in measuring outcome indicator, d. Determine when to administer the four-tier diagnostic test instrument, e. Design the four-tier diagnostic test instrument, and f. Pilot test and revise [19]. Pilot test and revised the instrument based on validity result from raters' score in content and construct validity.

### *2.2 Scoring Procedure of Four-Tier Diagnostic Test on Chemical Kinetics development*

To figure out the misconception that happened in learners, the four-tier misconception diagnostic test is an enhanced version of the two-tier test. This test includes the level of answers (tier 1), the level of learners' confidence in the correctness of the choices they choose for the level of answers (tier 2), the reasons each measure learners' content knowledge and explanatory knowledge (tier 3), and the level of confidence for reasons (tier 4) [20]. Validity data obtained from raters were then analyzed to answer the question of whether the product is valid or not through 5 rating scales, from 0 (very bad) to 4 (very good). The results of instrument validation (content and construct validity) based on the expert judgment from the raters were analyzed quantitatively and revised if necessary. There were four raters (lecturer of the undergraduate program of chemistry education and undergraduate program of chemistry), who give a score on content and construct validity. If an instrument is assessed by two or more raters and the total score is obtained by summing the ratings, there is a tendency to add up the scores and use the average but if the mean is skewed the median is an appropriate statistic for a person's score [21]. In this research, the validity determination uses the median model. The developed four-tier diagnostic test instrument is said to be valid if the median scores obtained for each criterion and question item reach $\geq 2.00$.

## 3. RESULTS AND DISCUSSION

### *3.1 Clearly Identify The Outcome*

Nowadays empirical studies show that learners have prejudices for many topics and that these prejudices are inconsistent with current scientific concepts [22]. It is essential in program evaluation to define the outcome, the change to be expected, clearly [19]. Likewise in a chemistry lesson, where evaluation can be done to observe whether learners have the correct understanding of the concepts that have been studied in learning a course. Evaluation of this course can be done by giving diagnostic tests to learners. A test is a measuring instrument that is intended numerically to describe the level or number of constructs under uniform standard conditions, where the most important of a test is interpretation validity and use of scores [21]. In this study, the researcher's aim is to gain a valid instrument that can be implemented to figure out concepts that experience misconception on learners.

### *3.2 Determine The Measurement The Outcome Achievement*

Data sources such as test, observation, survey, or interview. Test is one of the data sources used for knowledge-based questions (correct vs. wrong/incorrect or accurate vs. inaccurate) [19]. There are several types/forms of test, one of them is multiple-choice questions. Multiple-choice questions can provide useful diagnostic information about respondents' misconceptions about the subject matter with incorrect answer choices having to be written to include common errors or misconception.

### *3.3 Determine the Details to Measure Outcome Indicator*

In this stage, before starting to design a quantitative instrument, specific details need to be determined [19]. This research focuses on the misconceptions that occur in

learners who have taken kinetics courses. In addition, this study tends to develop diagnostic test questions for concept components, namely labels, definitions, attributes, and examples for Kinetics concepts.

*3.4 Determine When to Administer the Instrument*

It is necessary to determine when and how the test is carried out (called the evaluation methodology) [19]. For this study, the development of diagnostic test started at the beginning of the semester.

*3.5 Design the Instrument*

Test design is the initial stage of test execution in which the researcher states the claims to be made about the test taker, selects and defines the constructs to be measured, decides on the best way to measure them and produces detailed specifications of the test [23]. The instrument developed are the Four-Tier Diagnostic Test with Multiple Choice Test type of questions on the material of Chemical Kinetics. There are 19 questions. The questions presented refer to the components of the concepts discussed in the Chemical Kinetics course. Each definition of the concept and its character refers to literature textbooks that discuss specifically and comprehensively related to Chemical Kinetics. Questions are developed based on the following concepts: Reaction rate, Activated complex, Reaction rate law, Reaction order, Rate constant (k), Activation energy, Catalyst, Integral Rate Equation, Half-life, Reaction mechanism, Overall reaction, Elementary reaction, and Intermediate. The following will present the definitions of the concepts developed by the four-tier test instrument, and the possible misconception occur in learner:

The reaction rate is the change in the number of the reactant or product molecules per unit of time [24] [25] [26]. As an example of writing: r = d[HI]/dt. For the reaction under consideration, stoichiometry shows that moles of reactant B react every time one mole of reactant A disappears, so that B disappears b/a times faster than a [26]. Misconception in learner for the rate of reaction such as “if the reactant concentration increase, it will increase the reaction rate proportionally” [27].

Activated complexes are the molecular species present at maximum energy. These are the species when old bonds are broken followed by the formation of new ones: they are called active complexes [28]; [29]. The reactant order of reaction is the contribution (written as power) of reactants/product concentration to the rate law, and the overall reaction order is the sum of the powers of concentration involved in the rate law. [26] [24]. Misconception that can happen to learner such as “The order of reaction can be gained if chemical equation is balanced” [17] [27].

The rate constant k in the Arrhenius equation is the product of the pre-exponential factor and the exponential factor [25]. The rate constant is the rate of a reaction when the concentration of the reactants is one, under these conditions rate constant is also known as the specific rate or rate coefficient [24]. Activation energy is the least amount of energy required to activate reactant atoms or molecules to a state where they can undergo a chemical reaction to form products [26]. Catalyst is a substance that is a reactant and a product of a reaction; its concentration enters into the kinetic equation but does not enter into the equilibrium constant for the reaction [25]. Misconception that can be happened is “The reaction rate accelerate by catalyst; catalyst increases the activation energy” [30]. Another misconception: to initiate reaction, catalyst is needed but does not interact with the reaction species [27].

The integration method to determine the order of a reaction thus involves plotting the experimental data according to each of these integrated equations in turn, i.e. the expression of the integrated equation is plotted against time [31]. The half-life is time required for the reactant concentration to react to half of its initial concentration [32] [29].

Reaction mechanism: a postulated elementary reaction sequence that reflects the correct stoichiometry and predicts the correct rate law for the overall reaction [29] [31]. Many of the observed ("whole") chemical reactions consist of two or more basic reactions; such elementary reaction combinations are complex (or composite) reactions [32]. Since such a reaction can be shown to occur in several steps or stages, it is called an overall reaction [31]. Elementary reactions are those in which the order of the individual reactions is equal to the stoichiometric coefficients of the same chemical species [26]. A one-step reaction has one transition state; such a process is called an elementary reaction [32].

Time-free stoichiometry means that, within the accuracy of the chemical analysis used, the intermediate cannot be detected and so does not affect the stoichiometric relationship between the reactants and products [29].

Some of these concepts are interrelated and cannot be separated, such as the concept of intermediates with the concept of reaction mechanisms and the concept of elementary reactions. So that n the development of the test there are several concepts that are represented by the same question. By paying attention to the misconceptions that arise in several concepts, the researchers compiled a four-tier diagnostic test by including the possibility of misconceptions in the alternative answers in tier 1 and possible reasons in tier 3. Meanwhile, in tiers 2 and 4, it is the respondent's (learner) belief in the choice of answers for tier 1 and tier 3.

*3.6 Pilot Test and Revise*

To see how the instrument works and is useful for improving the accuracy and consistency of the instrument, the researcher has to conduct a pilot test [19]. In this study, pilot test is described as the determination of the content and construct validity of the instrument four-tier diagnostic test on Chemical Kinetics concept. Table 1 shows median assessment data of content and construct validity from 4 raters. Content validity is the result of a rater's/expert's assessment of the truth of the contents or the truth of the chemical kinetics concepts contained in the four-tier test misconception diagnostic test instrument. Content validity has been met if the substance of the contents of the diagnostic test is known to contain no wrong concepts (misconceptions). In table 1, content validity consists of the Suitability of questions with indicators (1a), the suitability of the answer to the question on Tier 1 (1b), and the suitability of the answer to the question on Tier 3 (1c). In construct validity, the rater provides an assessment score on the language and graphics. From the score value data obtained from the rater's assessment (with an assessment range of 0 to 4), the median of the scores was determined to obtain the validity category of each item of the question. For construct validity consist of good and correct Indonesian (2a), Appropriate terms and easy to understand (2b), short and clear language (2c), Type and size of the font used can be read (2d), and Text and images /tables/graphics layout (2e).

**Table 1.** Median in content and construct validity

| Question no. | Concept | Content Validity | | | Construct Validity | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1a | 1b | 1c | 2a | 2b | 2c | 2d | 2e |
| 5 | Ea and catalysts | 4 | 4 | 3.5 | 4 | 4 | 4 | 4 | 4 |
| 6 | | 4 | 4 | 3.5 | 4 | 4 | 4 | 4 | 4 |
| 7 | | 4 | 4 | 4 | 4 | 4 | 3.5 | 4 | 4 |
| 8 | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 9 | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 12 | half-life and integrals | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 16 | | 3.5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 10 | mechanisms, activated complexes, and elementary reactions | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 17 | | 4 | 4 | 3.5 | 4 | 4 | 4 | 4 | 4 |
| 18 | | 3.5 | 4 | 4 | 4 | 4 | 3.5 | 4 | 4 |
| 19 | | 4 | 4 | 3.5 | 4 | 4 | 4 | 4 | 4 |
| 2 | reaction order | 4 | 3 | 4 | 4 | 3.5 | 4 | 4 | 4 |
| 3 | | 3.5 | 3.5 | 4 | 4 | 4 | 4 | 4 | 4 |
| 4 | | 4 | 4 | 3.5 | 4 | 4 | 4 | 4 | 4 |
| 11 | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 1 | reaction rate and k | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 13 | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 14 | | 4 | 4 | 4 | 4 | 3.5 | 4 | 4 | 4 |
| 15 | | 3.5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

Note: valid if score ≥ 2

Based on Table 1, it can be described that all of the question items have met the content validity requirement. The median scores obtained for each criterion in each question number has reached 3.5 to 4, which is reach ≥ 2.00 for valid category. From the data in Table 1, the item with the lowest median in more than 1 aspect is question number 3. Construct validity is the result of an expert's assessment of the suitability of the question items with the measured content domain which is arranged in a specification table related to the ability to understand the concept of chemical kinetics (in language and graphics aspects). The instrument is said to meet the requirements of construct validity if the questions that make up the instrument are assessed by experts and declared valid (median score ≥ 2.00). Showed in Table 1, the assessment data from raters can be inferred that all 19 question items have met construct validity requirement. The median scores obtained for each criterion in language and graphics for each question number has reached 3.5 to 4 or reach ≥ 2.00 for valid category. Based on Table 1, shows that the questions, answer choices (tier 1), reason choices (tier 3), and beliefs (tier 2 and tier 4) indicate that the language used does not cause ambiguity. Likewise, the selection of images/data tables/ graphics also shows that the four-tier diagnostic test developed is appropriate and does not cause ambiguity. Ambiguity could be the cause of the respondent's misunderstanding in determining the content of the questions, answers, and reasons for choosing the answers so that the respondent's answers later cannot be ascertained whether it is due to a lack of understanding of the concept or because of language or confusing display.

3. The rate law that applies to the reaction $H_2 + I_2 = HI$ is $r=k[H_2][I_2]$. The reaction $H_2 + Br_2 = 2HBr$ is similar to the reaction for the formation of HI, so the rate law that applies to the reaction $H_2 + Br_2 = 2HBr$ is...

**Tier 1.** answer choices
a. Has a reaction rate of $r=k[H_2][Br_2]$
b. Has a reaction rate of $r=k[H_2]^2[Br_2]^2$
c. The reaction rate for HI formation is slower than the rate for HBr. formation
d. Unpredictable
e. The reaction rate for HBr formation is the same as the rate for HI. formation

**Tier 2.** Are you sure about your answer on Tier 1?
Yes ☐
No ☐

**Tier 3.** Argument choosing answers:
a. Elements of the same group have the same properties and the order of the reactions
b. The rate law of the reaction is directly proportional to the stoichiometry of the reaction equation
c. Iodine has a larger radius than bromine so it takes longer to react
d. The rate law of the reaction is obtained from the experimental results
e. Reactions with the same reactants or group elements have the same reaction rate

**Tier 4.** Are you sure about your answer on Tier 3?
Yes ☐
No ☐

**Figure 1.** Four-tier test on chemical kinetics matter

Figure 1 is an example of a four-tier test. In question number 3 consists of a question with one correct answer (d) and 4 distractors (shown in tier 1). In tier 3, there are 5 options to be selected the appropriate reason (d) for the answer given in tier 1 and 4 distractors. The distractors in tier 1 and tier 3 were adapted and/or adopted from learners' unscientific ideas obtained from the research findings and the researcher's teaching experience. Tier 2 (provided after tier 1) and tier 4 (provided after tier 3) contain the belief of the choices they choose for the level of answers (tier 2) and the level of confidence for reasons (tier 4). Tier 2 and tier 4 are linked to both tiers provide an important means of distinguishing between genuine misunderstandings and guesswork [17].

Understanding the prerequisite concepts that learners have must be identified before new concepts are learned by them. This is due to the interdependence of one concept with others, such as in a concept map. In order to avoid continuing misconceptions, the teacher must identify learners' misconceptions about the subject by applying a misconception test or interview with learners before learning and consider these misconceptions to correct them [15]. Diagnosis of understanding of concepts in chemical kinetics must be carried out before the delivery of the next material. Because it turns out that many unscientific ideas unfold can be explained by learners through combining the theory of chemical reaction kinetics with other topics in physical chemistry for example with chemical equilibrium [17]. After realizing learners' misconceptions, they must be eliminated so that learners better understand the reaction rate concepts [15], which is reaction rate is part of Chemical Kinetics concept. From data showed in Table 1 the median score for each question number has valid category both in content validity and construct validity. It means that the four-tier diagnostic test in Chemical Kinetics concept can be implemented to figure out the conception profile in undergraduate learners.

## 4. CONCLUSION

The development of four-tier diagnostic test in Chemical Kinetic concept has been tested for validity in content and construct aspects. In content validity and construct validity, all question items met the requirement for valid criteria. The results of the validity analysis as discussed above confirm that this instrument is transferable and can be used to identify learners' understanding with minor revisions. The conclusion regarding the validity of the four-tier diagnostic test that has been achieved allows researchers to implement it to students who have not and have taken chemical kinetics courses. Learners build their knowledge in various ways (one of them is by connecting the new knowledge obtained with their existing conceptual framework), so it is necessary to strengthen properly the knowledge that already exists in learners' thinking processes.

## AUTHORS' CONTRIBUTIONS

Bertha Yonata: conducting experiment, method and drafting manuscript; Suyono: Review manuscript; Utiya azizah: data analysis.

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