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Development of a STEM-Based Activity Sheet to Train Critical Thinking in Reaction Rates

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Abstract
This study aims to develop a feasible STEM-based Student Activity Sheet on reaction rate material to train students' critical thinking skills, based on aspects of validity, practicality, and effectiveness. The research employed a Research and Development (R&D) method using 4D model, which encompasses four sequential phases: define, design, develop, and disseminate. However, the implementation of this study is confined to the develop stage. The product was validated by two chemistry education experts and one chemistry teacher to assess content and construct validity. The practicality was evaluated through student response questionnaires and observation sheets, while its effectiveness was measured using pretest and posttest scores of critical thinking skills and learning outcomes analyzed through the N-Gain formula. The validation results showed a mode score of 4, which in valid category. The practicality test yielded a score of 92% from student responses and 97% from observation results, categorized as very practical. The effectiveness analysis demonstrated that most students achieved high N-Gain scores ($g \geq 0.7$) in critical thinking indicators, with a significant improvement in learning outcomes from an average pretest score of 63 to a posttest score of 85. These findings indicate that the developed STEM-based LAPD is valid, practical, and effective to train students' critical thinking skills on reaction rate material.

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INTRODUCTION

Chemistry is one of the branches of natural science that studies the characteristics, composition of matter, the composition of matter, the change of matter into new substances, and also the energy that makes these changes (Djarwo, 2019). One of the materials studied in the Chemistry subject is reaction rate. Reaction rate, characterized by the temporal change in reactant and product concentrations, serves as a core concept in Phase F chemistry. Learning Outcomes phase F reaction rate material in understanding chemistry is that students have the ability to analyze factors that affect reaction rate by applying process this includes a rigorous cycle of observation, hypothesis formation, experimental execution, and data synthesis. Consequently, students must demonstrate proficiency in designing, implementing, and defending experimental results that illustrate how specific factors modulate chemical kinetics. Reaction rate material is considered suitable for training critical thingking skills (Ramadhanti & Agustini, 2021).

The rapid development of the 21-st century certainly require everyone to have certain skills or competencies in order to be able to deal with it (Lin et al., 2018). In overcoming the global challenges of the 21-st century, human resources need skills that support flexibility, adaptation, and the ability to take action. An important 21-st century skill for facing global challenges is critical thinking (Misfalla, 2020). The implementation of problem-based learning provides a strategic space for students to hone their critical thinking skills through systematic exploration of solutions. According to Facione (1990), critical thinking is the ability that helps a person analyze and combine information to solve problems in a certain context. Indicators of critical thinking namely interpretation, analysis, explanation, evaluation, inference, and self-regulation (Facione, 1990).

The findings of a study conducted by Susilawati et al. (2020) indicated that 64% of participants demonstrated low critical thinking skills, while 15% were categorized as having very low critical thinking skills. The low critical thinking skills of students on each indicator were also confirmed by the results of a study by Sarip et al. (2022), which reinforced this data. The details are as follows: interpretation indicator at 36.62%, analysis at 13.58%, evaluation at 32.16%, and inference at 24.69%. In light of this evidence, it is evident that students' critical thinking abilities remain underdeveloped. This aligns with the findings of Riti et al. (2021), who argue that such deficiencies stem from a passive classroom environment. When instruction remains teacher-centric and students merely act as information recipients, the necessary conditions for fostering critical inquiry are not met.

Based on several relevant research facts, a learning approach is needed that trains critical thinking skills. To respond to the challenges of the times, the Science, Technology, Engineering, and Mathematics (STEM) approach has become a highly relevant instructional strategy in equipping students with 21st-century skills, especially in honing their critical thinking skills (Kusyanto et al., 2022). The STEM approach focuses on solving real problems in daily life (Pujiati, 2020). Consequently, a STEM-based curriculum fosters a diverse skill set, specifically cultivating inventive thinking, practical ingenuity, and the ability to work effectively in team (Susiyawati et al., 2022). In line with the 21st-century education paradigm, the learning process now focuses on Student Center Learning (SCL), which includes critical thinking, creativity, communication, and collaboration skills known as 4C (Khoiri et al., 2021). In this context, the STEM approach is considered a highly relevant strategy because it accommodates various characteristics of modern learning that are holistic, scientific, contextual, thematic, and still based on teamwork (Davidi et al., 2021; Novitasari et al., 2022). Selection of the STEM approach in the learning process can develop skills to create solutions, innovate independently, and connect learning outcomes with real phenomena (Widya et al., 2019). A study conducted by Lestari and Muhajir (2021) further supports the claim that the STEM approach can enhance critical thinking skills. Moreover, the STEM approach emphasizes problem-solving, which is one of the key strategies for developing students' critical thinking abilities.

STEM approach focuses on solving real problems in daily life (Pujiati, 2020). Thus, the STEM approach has a strong relationship with reaction rate materials because both require high-level thinking skills, and problem-solving. An evaluation of Phase F learning outcomes reveals that students must demonstrate the ability to examine variables influencing reaction rates through the comprehensive application of process skills, from planning to evaluation, of course, are very aligned with the STEM approach. In the context of STEM, the Science aspect is used by students to observe, question, predict, analyze and conclude data, the Engineering aspect is used to plan experiments, the Technology aspect is used when conducting investigations such as using stopwatches, and the Mathematics aspect is used when analyzing data such as calculating reaction rates. Thus, the application of STEM to reaction rates makes learning an active process of investigation and design, thereby holistically meeting the learning outcomes requirements for training students' critical thinking skills.

The learning approach will run optimally if supported by using teaching materials as a medium in classroom learning activities. One of the teaching materials used by teachers is the Student Activity Sheet. Student activity sheet is teaching material that contains instructions and information from the teacher to student to carry out tasks, whether in the form of practical work, learning activities, or the application of activities aimed at achieving the desired learning outcomes (Nur, 2020). LAPD serves to create dynamic interactions between teachers and students during learning, where students are encouraged to actively participate through measured discussion and experimentation activities (Pertiwi et al., 2021). Evidence suggests that integrating STEM-based LAPD significantly elevates students' critical thinking abilities to a proficient level. This improvement is underscored by the findings of Kiswanto et al. (2024), where mean scores surged from an initial 50.30 in the pretest to a substantial 89.69 in the final posttest. In line with this, Lestari et al. (2018) revealed that the use of STEM in LAPD contributed positively to improving the indicators of inference, interpretation, and evaluation in students.

In light of the issues previously outlined, there is a clear need to strengthen students' critical thinking abilities. Accordingly, this study seeks to develop a STEM-based student worksheet that meets feasibility standards as evaluated through its validity, practicality, and effectiveness. Previous studies by Sihombing et al. (2022) and Syafira and Effendi (2020) have demonstrated the potential of student activity sheet, including those based on STEM approaches, to support active learning and improve classroom practices. These studies contributed to the development of feasible and practical instructional materials and provided initial insights into the implementation of activity-based learning.

Building upon and extending these prior works, the present study maintains the use of a STEM-oriented approach in student activity sheet development, thereby establishing continuity with earlier research. At the same time, it introduces several key novelties. First, this study explicitly integrates five critical thinking indicators (inference, interpretation, analysis, evaluation, and explanation) into both the design of leaming activities and the assessment components of the worksheet. Second, it conducts a comprehensive effectiveness analysis that examines the impact of the worksheet on each specific indicator of critical thinking, rather than relying solely on general learning outcomes. Third, in the context of chemistry education, particularly on the topic of reaction rates. This study proposes a structured framework for aligning STEM-based worksheet design with operationalized critical thinking constructs, which has not been systematically addressed in previous studies.

Therefore, this study makes a distinct scientific contribution by bridging the gap between STEM-based instructional design and the explicit mesasurement of critical thinking skills, while simultaneously extending and refining the contributions of earlier worksheet & development research.

METHOD

This study employs a Research and Development (R&D) design aimed at producing a student activity sheet grounded in the STEM approach to facilitate the development of students' critical thinking skills in the topic of reaction rates. The development process adopts the 4D model, which encompasses four sequential phases: define, design, develop, and limited disseminate stage.

Define Stage

The definition stage focuses on identifying fundamental problems and learning needs in reaction rate teaching. This stage aims to analyze problems during learning, analyze student characteristics, analyze assignments, analyze concepts and formulate learning objectives. The findings derived from this phase establish the essential foundation for identifying and developing effective problem-solving strategies, identifying the need for student activity sheet STEM, determining the relevant reaction rate content, and determining learning objectives.

Desgin Stage

The design stage involves an initial design that is compiled based on the previous analysis stage and prepared to enter the trial stage. At this stage, the researcher formulates the preliminary design of the product by referring to the outcomes of the concept analysis, task analysis, learner analysis, and the predetermined instructional objectives. The student activity sheet draft that has been drafted will be validated by experts before proceeding to the limited trial stage.

Develop Stage

The development stage consists of expert validation, product revision, and development trials. The developed media is evaluated by three experts in terms of construct validation and content validation. Based on the feedback of experts, revisions were made to improve the quality of the media. Subsequently, a limited field trial was carried out to evaluate the practicality of the STEM-based student worksheet. The treatment was conducted over five lesson periods with eachperiod lasting 45 minutes. This phase involved 10 eleventh-grade students and devided to four groups of Al Falah High School as the research participants. One specific eleventh-grade class was chosen because they were currently studying the topic of Reaction Rates and exhibited a heterogeneous range of academic abilities based on preliminary research findings.

The participants consisted of students aged 15 to 17 years old. Regarding their prior knowledge and experience, these students were characterized by the fact that they had never previously used STEM-based student worksheets specifically for the topic of reaction rates. This specific characteristic makes then an ideal group for evaluating the effectiveness of the newly developed STEM-oriented worksheet in fostering the five indicators of critical thinking.

Data Collection and Analysys

The feasibility of the developed student activity sheet was determined through the analysis of validation results, practicality data, and effectiveness data. The validation process involved two experts in chemistry education and one practicing chemistry teacher. To facilitate this process, the researcher designed a validation instrument in the form of an expert appraisal sheet, which was completed by the validators. The evaluation employed a Likert scale scoring system, as presented in Table 1 below.

Table 1. Likert Scale Score

Score	Criteria
1	Not valid
2	Less valid
3	Fairly valid
4	Valid
5	Highly valid

(Hobri, 2021)

The validation results, presented in the form of ordinal data, were subsequently analyzed using descriptive quantitative techniques. The analysis was conducted for each indicator by determining the mode value to identify the most frequently occurring rating. Thus, the student activity sheet developed is declared valid if it obtains a score of ≥ 3. But if the three score data do not have the same score value, it can use the median to avoid chaotic data distribution. The median itself means the Middle value of the data that has been sorted. The student activity sheet is declared valid if a score of ≥ 3 is obtained. If the student activity sheet is invalid, then the researcher needs to revise the student activity sheet.

Analysis of practicality data derived from observation sheets and student response questionnaires is quantitative data analyzed using percentage scores. The formula used for quantitative analysis is as follows.

$$\text{Percentage} = \frac{\Sigma \text{ score of each item}}{\max score\ of\ each\ item} \times 100\%$$

Table 2. Interpretation of the Guttman Scale

Score	Criteria
1	Not practical
2	Less practical
3	Fairly practical
4	Practical
5	Highly practical

(Denisa & Astimar, 2024)

The STEM-oriented student worksheet is deemed practically viable provided it attains a minimum practicality score of 61%.

The effectiveness of the product was evaluated through a critical thinking skills test and a learning achievement test. These assessments were administered to determine the effectiveness of the instructional implementation, as indicated by the differences in students' scores before and after the learning process. It should be noted that the effectiveness findings of this study are limited in scope, as they are based solely on a small scale (limited) trial and have not yet been validated through broader implementation. The formula for calculating N-Gain is as follows:

$$Normalized\ Gain\ (g) = \frac{Posttest\ Score - Pretest\ Score}{Maximum\ Score - Pretest\ Score}$$

The N-Gain score are interpreted on the criteria that can be seen in Table 3 below.

Table 3. N-Gain Score Criteria

Score	Criteria
$g \geq 0.7$	High
$0.7 > g \geq 0.3$	Medium
$g < 0.3$	Low

(Hake, 1999)

Based on the results of data analysis, the student activity sheet is declared effective if there is an improvement in students' skills as measured through an N-Gain score with a minimum score of 0.3 which is included in the medium category. Then calculations are carried out to find the completeness of individual learning with the following formula.

$$\text{Individual Completeness} = \frac{Total\ score\ obtained}{maximum\ score} \times 100\%$$

In accordance with the learning Objective Achievement Criteria of the subjects in the school studied, students are declared complete if the score obtained ≥ 80.

RESULTS AND DISCUSSION

Define Stage

The definition stage begins with the front end analysis, which is carried out to identify problems that arise in the learning process, so that it can be used as a background for development research to be carried out (Thiagarajan, 1974). Furthermore, the analysis of students aims to identify their academic abilities as well as their level of cognitive development. Followed by task analysis to determine the learning materials to be presented. The next stage is concept analysis to organize it in detail and systematically by relating each interconnected concept so that a concept map is formed on the reaction rate material. The last stage is formulating learning objectives.

Desgin

This stage aims to design STEM-based Student Activity Sheets as a tool to facilitate the development of students' critical thinking skills on the topic of reaction rates. During the design phase, the initial product was developed through four main steps: instrument development, selection of appropriate learning media, determination of the worksheet format, and initial writing of learning materials. Figure 1. contains illustrations of the student activity sheet.

Figure 1. Student Activity Sheet

The student activity sheet cover will be differentiated according to the reaction rate factor, the science aspect of students observing the phenomena in the student activity sheet , the Technology aspect of students scanning the QR code for which will lead to the Google Sheets web to make an observation table, the engineering stage of students making a series of tools and procedures, on the mathematical aspect of students calculating the reaction rate.

Develop Stage

Validation

The validation of the developed media was evaluated by three experts on the validity of the content and construct criteria. The learning media developed obtained a mode score of 4, indicating that the media met the validity criteria. In the aspect of content criteria that assess the suitability of the media with concepts, suitability with STEM, suitability with critical thinking skills, get mode 4 with valid criteria. On the validity of the construct criteria that assess aspects of presentation, language and graphics, the mode 4 is obtained. In the aspect of presentation, one of the things that was assessed was cover, which was made interesting and represented the content. this is because student activity sheet covers that have the right color, image, shape, and font of letters can attract students to the student activity sheet developed (Indriani, Yuniar, & Pratiwi, 2023). The language component aims to determine the suitability of the student activity sheet with the linguistic criteria of obtaining mode 4. the use of clear language and adjusted to the level of understanding of students makes teaching materials more effective in supporting the achievement of learning goals (Indriani, Yuniar, & Pratiwi, 2023). The third component evaluated was the graphic elements, which aimed to assess the suitability of the visual design of the student activity sheets and obtain a mode score of 4. Once validated, the developed media proceeded to limited field testing to test the feasibility of the student activity sheets. The participants involved in this stage are grade XI students at Al Falah High School

Practicality

The practicality stage is measured through response questionnaires and observation sheets of student activities. Response questionnaires were given to students who had participated in a limited trial of the developed media. Student activities were observed by four observers, where each observer was responsible for monitoring student engagement during the learning process. Observations were recorded using an activity observation sheet at 3 minute intervals throughout the lesson. The student activity sheet that has been developed shows a practicality rate of 92% and falls into the category of very practical. One of the duties of teachers as educators is expected to develop an interesting and characterful student activity sheet, This approach served to bolster student engagement and foster a heightened sense of academic curiosity, thereby creating a more dynamic learning environment about the content in the student activity sheet (Hairani, Safruddin, & Setiawan, 2022). The results of the percentage of observations at the first to fourth meetings showed that 97% of relevant activities and 2.08% of irrelevant activities were included, so they were included in the very practical category. The observation results are detailed in Table 4 below.

Table 4. Observation Result

Student activities	Percentage of observation results				Average
	Session 1	Session 2	Session 3	Session 4	
Relevant	96,7%	96,7%	98,3%	100%	97,92%
Irrelevant	3,3%	3,3%	1,7%	0%	2,08%

Relevant activities include students observing problem phenomena in the developed media, including science aspects This activity is in line with the STEM approach focusing on real problem solving in everyday life .(Pujiati, 2020). The technological aspect can be observed when students Scan *Qr Code* which will display on the web Google Sheet so that students can create observation tables. *Engineering* Aspects learned by designing equipment and procedures refer to tools and materials that have been adjusted to the student activity sheet (Rukmansyah, 2020). Mathematics aspects of students will calculates the reaction rate. According to Najah, Sarifah, and Yunus (2025)) by calculating, it can find out the analysis indicators of students.

Effectiveness

The effectiveness phase involved an examination of normalized gain (N-Gain) metrics regarding critical thinking skills, alongside an analysis of how well students achieved the required standards of conceptual understanding. Critical thinking skills tests are carried out before and after using the developed media. This test contains 9 description questions that use five of the six indicators, namely interpretation, inference, analysis, evaluation, and explanation. It consists of 3 interpretation questions, 3 inference questions, 1 analysis question, 1 evaluation question, and 1 explanatory question. The score was determined and the results of N-Gain are detailed in the table 5.

Table 5. N-Gain Score Criteria

Indicator	Pretest	Posttest	N-Gain	Categories
Interpretation	31	83	0,86	High
Inference	27	78	0,81	High
Analysis	6	26	0,84	High
Evaluation	7	25	0,78	High
Explanation	9	25	0,76	High

The results of this study indicate that the STEM-oriented student activity sheet (LAPD) was effective in improving students' critical thinking skills across all five indicators, although with varying levels of improvement. The most prominent finding is that the Interpretation indicator achieved the highest N-Gain, while the explanation indicator showed the lowest Improvement.

The high improvement in interpretation skills can be explained from a theoretical perspective. Interpretation, as defined by Facione (1990), involves understanding and conveying meaning from data, phenomena, and representations. This skill represents a fundamental level of critical thinking that is closely associated with identifying variables, formulating problems, and interpreting experimental data. The developed worksheet consistently trained these processes through structured activities such as identifying manipulation and response variables, organizing observation data into tables, and linking phenomena to guiding questions. From a STEM perspective, these activities strongly reflect the science and mathematics components, where students engage in observing, classifying, and organizing data. Because these tasks are relatively structured and familiar, students are cognitively more prepared to perform them. This explains why interpretation showed the highest improvement, which is consistent with previous findings that students tend to perform better in meaning-making tasks due to frequent exposure in science learning (Agustine & Nawawi, 2020;

Sumargono et al., 2022). In contrast, the explanation indicator showed the lowest improvement. Theoretically, explanation is a higher-order thinking skill that requires students not only to understand data but also to construct logical arguments, justify relationships between variables, and connect empirical findings with scientific theories (Facione, 1990). This process demands complex cognitive integration and argumentation skills. Although the worksheet provided opportunities for discussion, experimentation, and observation, the scaffolding for constructing scientific explanations may not have been sufficiently explicit. In the context of STEM integration, while the engineering and technology components supported experimentation and data generation, they did not fully facilitate students in transforming their findings into well-structured arguments. This limitation explains why students' explanation skills improved the least. This finding aligns Indiarti et al, (2022) study that students often struggle to provide clear reasoning and justification in their answers.

The improvement in other indicators, such as inference, analysis, and evaluation, can be attributed to the specific design features of the worksheet. The integration of problem-based tasks, experimental activities, data representation (tables and graphs), and guided questions enabled students to actively engage in identifying relationships, formulating hypotheses, analyzing data patterns, and evaluating results based on theory. These activities reflect the integration of STEM components: science (understanding concepts), technology (using data and representations), engineering (designing and conducting experiments), and mathematics (analyzing quantitative relationships). Such integrated and iterative learning experiences provide repeated practice, which is essential for developing critical thinking skills (Alsaleh, 2020), In particular, group discussions during worksheet completion also contributed to students' ability to construct inference and evaluation, as they were required to negotiate meaning and justify their reasoning collaboratively.

In the student learning outcome test questions, there are 10 multiple-choice questions regarding reaction rate material sub-chapter reaction rate factors. Pretests are conducted before students use the developed student activity sheet and posttests are conducted before students use the developed student activity sheet. The average initial ability of students is low towards reaction rate material so that the average result is 63 which indicates that many students are not complete in doing the knowledge pretest. After that, students were given treatment by doing student activity sheet with a STEM approach, the average increased to 85, which indicates that many students have completed their posttests.

CONCLUSION

This study shows that STEM-based Student Activity Sheets on reaction rate material, designed to train students' critical thinking skills, are feasible for use as they meet the criteria of validity, practicality, and effectiveness. The validity of STEM-based Student Activity Sheets was evaluated based on their coverage of factors such as temperature, catalysts, surface area, and concentration. Each aspect received a mode score of 4, which in valid category. Consequently, it is evident that the developed Student Activity Sheet fulfills the predefined validity standards.

The practicality of the student activity sheet was evaluated using student response questionnaire and classroom activity observations. The student response questionnaire produced a score of 92%, which falls into the "very practical" category, while classroom observations achieved a score of 97%, also classified as "very practical". These findings demonstrate that the developed student activity sheets comply with the established practicality standards.

The effectiveness of the student activity sheets was determined through pre-post tests of students' critical thinking skills. Where all critical thinking skill indicators, namely interpretation, inference, analysis, evaluation, and explanation, received high ratings, which means that the LAPD developed was effective.

RECOMMENDATION

It is suggested that subsequent research expands its scope to encompass all six indicators of critical thinking: interpretation, inference, analysis, evaluation, explanation, and self-regulation. Furthermore, while this study specifically focused on reaction rate factors, future investigations could explore the application of these student activity sheets across diverse chemical topics.

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