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Interactive E-Worksheets for Critical Thinking in Chemistry : A Three-Level Representation Approach to Voltaic Cells

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Abstract: This study aims to investigate the impact of interactive electronic worksheets combining three chemical representation levels on students' critical thinking skills in learning voltaic cells. This research utilises an R&D (Research and Development) method featuring a one-group pretest-posttest design. The participants in this study were 12th-grade high school students. The tools used in this research included validation sheets, pretest-posttest assessments, and feedback questionnaires. Validation data indicated that the e-worksheets were suitable for testing, achieving a median score of ≥ 4. The pretest-posttest results were analysed using the N-Gain score, which fell within the range of 0.7 to 0.9. Additionally, a paired t-test was conducted using the Minitab software, yielding a p-value of less than 0.05, signifying a meaningful enhancement in students' critical thinking skills. The feedback from students regarding this media resulted in a practicality rating of $\geq 61\%$. In summary, interactive e-worksheets based on the three levels of chemical representation have been demonstrated to improve students' critical thinking skills.

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Introduction

Chemistry is a branch of science integrated with concrete and abstract concepts in learning (Danila & Agustini, 2021). This concrete concept is related to everyday events related to chemistry. Abstract concepts in chemistry are related to the characteristics of chemistry involving atoms, ions, and molecules that are too small to be seen even using an optical microscope. Based on this, chemical concepts are represented in three levels, namely macroscopic, symbolic, and submicroscopic representations (Gilbert & Treagust, 2009).

Voltaic cell material is one of the main topics of chemistry learning studied by students in high school (Alya et al., 2023). It is electricity-related, combining several scientific principles such as chemistry and physics (Aisyah et al., 2019). Voltaic cells have a concept based on electrolyte solutions and redox reactions (Tewal et al., 2021). Voltaic cells explain electrolysis reactions involving the movement of electrons that cannot be observed by the five senses (Sutantri, 2022).

The concept of a voltaic cell in macroscopic representation can be understood through the formation of deposits and the voltage that appears in a voltaic cell experiment (Sutantri, 2022). The submicroscopic representation is related to explaining the movement of electrons and ions during the voltaic cell process (Helsy et al., 2017). The symbolic representation is expressed in cell notation and the calculation of E cells (Sutantri, 2022). In general, the difficulty for students is describing and connecting what happens in macroscopic observations to the submicroscopic and symbolic levels so that the concept of voltaic cells cannot be fully understood (Yola & Kurniawati, 2023).

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The characteristics of voltaic cell material are closely related to critical thinking skills. In voltaic cell material, students must analyse and evaluate experimental data, interpret experimental data, and propose hypotheses, problem-solving, and explanations of phenomena (Redhana, 2019). Critical thinking skills are crucial for students learning in schools because they are the key to facing challenges in the 21st century (Sadiah et al., 2024).

Based on pre-research activities at one of the state high schools in Surabaya, the critical thinking skills of one of the XII sains classes were low. The information gathered while answering essential questions of thinking with six components, including (1) interpretation 51.85%, (2) explanation 50%, (3) analysis 38.27%, (4) evaluation 56.79%, (5) inference 39.51% and (6) self-regulation 37.50%. These data show that students' critical thinking skills are still low and need to be improved.

Critical thinking skills can be improved and trained with learning oriented towards three chemical representation levels. Representation in chemistry has three main functions: limiter of interpretation, complement, and concept builder (Mulyani et al., 2022). Three chemical representation levels can facilitate meaningful learning and encourage students to develop scientific knowledge (Rahmawati, 2015). These three levels of representation can be presented using learning resources such as E-worksheets (Yola & Kurniawati, 2023).

Worksheets are a learning medium that can encourage student independence and activeness and make it easier to understand the concepts being studied (Ayunda & Azhar, 2023). Worksheets are generally found in printed form and have several disadvantages, such as lack of interactivity and the inability to display clear animations related to the studied material. Printed worksheets can be more interactive using the live worksheet web (Arifianti & Dwiningsih, 2022). Worksheets developed using the liveworksheet web have several editing features, such as inserting video, audio, and images (Prasetyo & Novita, 2023). Web live worksheets are also easy to use and can be accessed from any smartphone or laptop without downloading a specific application (Yuliana et al., 2023).

Based on the description above, this study aims to investigate the impact of interactive electronic worksheets combining three chemical representation levels on students' critical thinking skills in learning voltaic cells. Developing interactive learning media based on three levels of chemical representation for voltaic cell material is urgent because students' critical thinking skills are still relatively low, and there are limited learning media that integrate the three levels of chemical representation. Although previous studies have explored digital worksheets in chemistry, few have explicitly included three levels of representation to enhance critical thinking, as in the survey conducted by Aini & Putri (2024) and Yola & Kurniawati (2023), which discussed the application of E-LKPD to enhance critical thinking skills but did not include three levels of representation in it.

Research Method

This research utilises an R&D (Research and Development) method featuring a one-group pretest-posttest design (Hardani et al., 2020). This design allows researchers to measure changes or improvements in the same group after using the developed interactive electronic worksheet (Sunarya & Atmazaki, 2024). This method uses three chemical representation levels to assess how practical interactive worksheets enhance critical thinking skills, particularly regarding voltaic cell concepts. Participants in this study were grade XII science students at a public high school in Surabaya.

The research conducted is classified as R&D (Research and Development) research, which is comprised of four key phases (Thiagarajan, 1974), namely:

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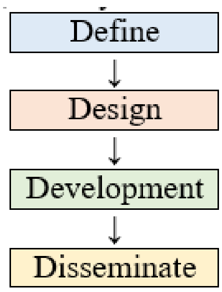

Figure 1. Research Procedures
Source: (Thiagarajan, 1974)

Thiagarajan's stages (4-D model: Define, Design, Develop, Disseminate) are often limited to the Develop stage for practical and strategic reasons. The dissemination stage requires significant resources, time, and effort to disseminate a product. At the same time, the primary focus of small-scale or educational projects is on product creation and testing, not mass distribution. As a result, many projects stop at the development stage after ensuring the product meets its intended purpose without moving on to widespread distribution.

At the defined stage (secondary data collection), student analysis, learning objectives, and media selection are determined. At the design stage, the media to be developed is planned by making concepts, storyboards, and layouts of the developed e-worksheets. Researchers create the designed e-worksheets at the development stage and validate them with materials, media, and pedagogy experts. Furthermore, a feasibility test is carried out by conducting a trial on students.

The research design used to collect data uses a one-group pretest-posttest. The data collection implementation stage begins with pretest questions before treatment, which measure students' initial critical and cognitive thinking abilities (Hardani et al., 2020). After that, learning continued using interactive e-worksheets for several meetings designed according to the curriculum's time allocation. The learning process utilises chemical representations at the macroscopic, submicroscopic, and symbolic levels to facilitate students' conceptual understanding. Once the learning sessions ended, students participated in posttest questions designed to assess their critical thinking abilities after utilising the media. Additionally, students completed a survey regarding their reactions to learning with e-worksheets.

The data collected through pretest and post-test scores were evaluated quantitatively using the calculation of N-Gain Scores (Hake, 1998). The gain score value is then averaged, and the results of the N-Gain calculation are used to determine the effectiveness of the Interactive E-LAPD developed with the following criteria:

Table 1. Gain Score Criteria

Score	Criteria
$<g> \geq 0,7$	High
$0,7 > <g> \geq 0,3$	Medium
$<g> < 0,3$	Low

The use of e-worksheets structured around three levels of representation was deemed sufficient if every student obtained an N-Gain score falling between 0.3 and 0.7, categorised as medium, or 0.7 and above, classified as high (Hake, 1998).

Moreover, the pretest and posttest values were analysed using paired t-tests to evaluate the improvement in critical thinking skills and the significance of this enhancement. If the p-value is more significant than 0.05, the null hypothesis (Ho) is retained, while the alternative hypothesis (Ha) is dismissed; this suggests that there is no notable difference seen

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before and after the treatment is implemented (Santoso, 2019). Statistical tests were conducted using the Minitab application. Minitab was chosen because it can perform accurate statistical analysis and professional data visualisation, especially in research quality control (Irawan & Suyono, 2024). The data from the students' responses to the questionnaire were analysed using the Guttman Scale. The Guttman Scale only uses two intervals, namely yes or no. The data from the questionnaire, using the Guttman Scale, is calculated as a percentage and is stated as practical if it gets a result of ≥ 61% (Riduwan, 2016).

Results and Discussion

A research initiative aims to assess students' critical thinking skills through interactive e-worksheets concentrating on three chemical representation levels. In the first stage, namely definition, students were investigated by conducting interviews with one of the chemistry teachers. Considering the interview findings, grade XII students at SMA Negeri 14 Surabaya display low interest in learning and inadequate critical thinking abilities. Therefore, it is essential to incorporate learning media that engage students' interest in studying and enhance their critical thinking skills.

Creating interactive e-worksheets can increase learning interest, while e-worksheets oriented towards three levels of chemical representation can improve critical thinking. Representation has three main functions: improving interpretation, limiting understanding, and promoting comprehension. (Mulyani et al., 2022). Three chemical representation levels can facilitate meaningful learning and encourage students to develop scientific knowledge (Rahmawati, 2015).

During the design phase, the media to be produced is planned through concepts, storyboards, and layouts of the e-worksheets that are designed. The e-worksheet is designed to incorporate three levels of representation, along with interactive elements such as animations, drag-and-drop activities, quizzes, and immediate feedback, while also promoting learning tasks that enhance critical thinking skills. The essential elements of thinking are interpretation, analysis, evaluation, inference, explanation, and self-regulation (Facione, 2015). Earlier research has investigated the application of digital worksheets in chemistry, yet only a limited number have explicitly incorporated the three levels of representation to improve critical thinking. The following is an initial view of the e-worksheet that was developed:

Cover Critical Thinking Aspects Chemical Representation

Figure 2. Interactive e-Worksheets

At the development stage, after the e-worksheet has been developed, validation is carried out by experts in the fields of material, media, and pedagogy. Validation is carried out to ensure that the e-worksheets meet the eligibility standards regarding material, media, and pedagogy. The research instrument, which consisted of pretest-posttest questions and student response

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questionnaires, was also validated. This study had three validators composed of 2 expert lecturers and one chemistry teacher. The following table showcases the outcome of the validity test:

Table 2. Validity Result

Aspects of Validity	Mode	
	e-worksheets 1	e-worksheets 2
Content Validity	5	4
Construct Validity	4	4

Based on Table 2, the validity of interactive e-worksheets meets the valid criteria because the median obtained is ≥ 4. The assessment data above for each indicator is declared valid using the provisions if the median that appears is at least 4. If the median seems less than 4, the media must be revised and returned to the validator for revalidation (Haladyna & Rodriguez, 2013). This is by research by (Lindawati et al., 2019) that interactive e-worksheets based on three levels of chemical representation can be used to help improve students' critical thinking skills.

The next stage is a limited trial conducted at SMA Negeri in Surabaya. This trial aims to obtain pretest-posttest value data and student response questionnaires after learning activities with interactive e-worksheets based on three levels of chemical representation. Students' critical thinking outcome is assessed following their pretest and posttest activities. The enhancement of students' critical thinking abilities can be evaluated by computing the normalised gain value from their pretest and posttest scores. The data regarding the pretest and posttest scores can be found in Table 3.

Table 3. Pretest and Posttest Data

Component Critical Thinking Skills	Pretest Score	Posttest Score	N-Gain score	Category
Interpretation	26,6	89,2	0,852861	High
Analysis	29,5	90,2	0,860993	High
Evaluation	21,9	91,1	0,886044	High
Inference	31,4	89,2	0,842566	High
Explanation	22,8	83,3	0,783679	High
Self-Regulation	30,9	90,8	0,86686	High

Table 3 showcases the data from the pretest and post-test related to the six dimensions of critical thinking skills: interpretation, analysis, evaluation, inference, explanation, and self-regulation. The pretest scores varied between 21.9 and 31.4, whereas the post-test scores significantly increased, ranging from 83.3 to 91.1. The N-Gain scores for each component were notably high, with values spanning from 0.783679 to 0.886044. This indicates that the intervention effectively improved students' critical thinking skills (Hake, 1998). This corresponds with findings from Prasetyo & Novita (2023) and (2022), suggesting that training with suitable learning media can enhance critical thinking skills.

The chart illustrates the growth in students' critical thinking abilities across each element from the pretest to the posttest. This aligns with Dwiningsih et al. (2023), which indicate that essential thinking abilities can be enhanced through training that utilises suitable learning media.

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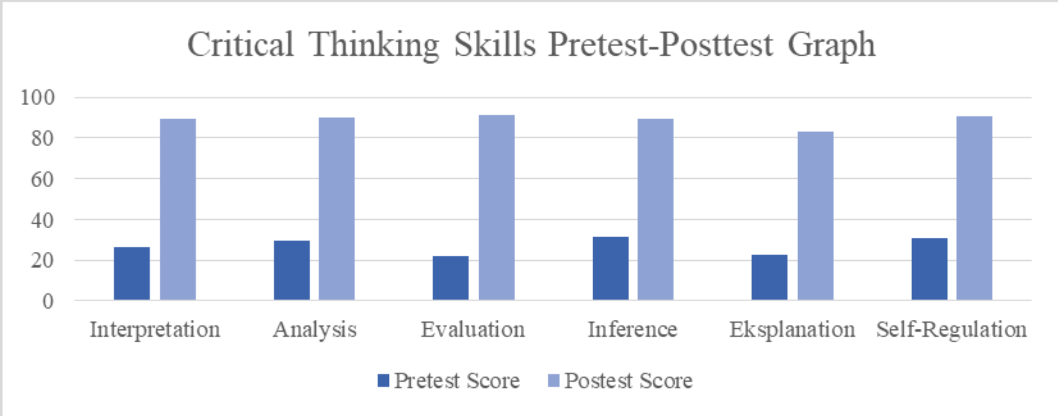

Figure 3. The enhancement of students' critical thinking abilities in every aspect.

The data from the table shows that after utilising interactive e-worksheet media, students exhibited enhanced critical thinking skills, as evidenced by their pretest and posttest scores. This is consistent with the results of (Asmara et al., 2019), which suggest that the initially low scores among students can be understood as a result of incomplete learning activities. The pretest-posttest data was analysed using statistical tests using Minitab; the following results were obtained:

Test

Null hypothesis H_0: μ_difference = 0
Alternative hypothesis H_1: μ_difference ≠ 0

T-Value	P-Value
-52,02	0,000

The paired t-test analysis using the Minitab application showed a T-value of -52.02 and a P-value of 0.000. The null hypothesis tested stated that the average between the data before and after treatment was the same, while the alternative hypothesis stated that the average was different.

The P value of 0.000 falls below the standard significance threshold (e.g., $\alpha = 0.05$), leading to the rejection of the null hypothesis. This suggests a statistically significant difference in the averages of the data collected before and after the treatment. A sizeable absolute T-value of -52.02 signifies a substantial treatment effect on the data. As a result of the limited trial conducted, responses from the student questionnaires provided data that helped assess the practicality of the interactive e-worksheet developed around chemical representation. After the limited trials, the student questionnaires were distributed and analysed quantitatively and descriptively, as shown in Table 4.

Table 4. Result of Students Response Questionnaire

Rated aspect	Percentage (%)
I can easily use interactive e-worksheets.	100
interactive e-worksheets do not contain words that have double meanings and confuse me	98
The interactive e-worksheets I use make me interested in studying chemistry, especially the topic of voltaic cells.	99
Interactive e-worksheets can guide me to observe, analyse, evaluate, conclude, and explain phenomena related to voltaic cells in daily life.	90
Interactive e-worksheets help me understand the material as a whole.	100

The outcomes were at least 61% for every question in the student response questionnaire, concluding that it was effective. Additionally, the student survey features a part for recommendations and feedback about the teaching tools, particularly the interactive e-worksheets being created. The responses from the students indicated a desire for more images connected to the content to enhance engagement and facilitate learning in chemistry, particularly with the topic of voltaic cells.

This study proves that interactive electronic worksheets integrating three chemical representation levels can improve students' critical thinking skills. Lindawati et al. (2019) conducted research that found that learning media combining three chemical representation levels can improve students' critical thinking skills. In addition, based on the results of the student response questionnaire, it can be concluded that learning using the developed interactive e-worksheets made them more interested in learning, especially in chemistry subjects, so their understanding increased. Students' critical thinking skills also improved. This is based on research conducted by Lathifah (2020), which states that learning media is an alternative that can be used to fulfill students' competencies in the 21st century, especially critical thinking competencies.

The study highlights that interactive electronic worksheets using three levels of chemical representation enhance students' critical thinking skills. It emphasizes the importance of multimedia learning for developing interconnected understandings of chemical concepts. The findings suggest that technology can transform education by promoting inquiry-based learning. Practically, it advises educators and policymakers to integrate these tools into chemistry education while providing necessary training for teachers. It also calls for a shift in assessment practices to prioritize critical thinking and problem-solving over rote memorization. Overall, the study validates the effectiveness of interactive worksheets and offers guidance for improving educational practices.

Conclusion

Based on the research findings, interactive e-worksheets can significantly enhance students' critical thinking abilities. The feasibility of this media is validated through content validity and construct validity and both categorized as valid. Concerning practicality, the feedback from the student response questionnaire across all evaluated aspects, confirming its practicality. Furthermore, the effectiveness of the interactive e-worksheets is demonstrated by the results of the pretest-posttest analysis conducted with a paired t-test that indicating a significant enhancement in students' critical thinking abilities after utilizing this media. The N-Gain score analysis also showed that the improvement in essential thinking skills fell within the high category.

This study confirms the effectiveness of interactive e-worksheets incorporating three levels of chemical representation in improving students' critical thinking skills. Future research should explore its application in diverse learning environments and with varied student demographics.

Recommendation

Interactive e-worksheets need to be further developed on the interactive design of e-worksheets by adding more complex chemical representation variations or different application contexts, such as lithium-ion batteries or fuel cells. This can broaden students' understanding not only of voltaic cells but also of current electrochemical technologies. In addition, further research can test the effectiveness of e-worksheets in more diverse learning settings, such as in schools with limited facilities or at different levels of education (e.g., high school vs. college). This will help evaluate whether this method can be widely adopted.

Possible obstacles areas for further research include limited access to technology in some schools, especially in remote areas, which may affect the implementation of e-worksheets. In addition, differences in students' background knowledge and varying critical thinking skills may pose challenges in consistently measuring this method's effectiveness. Therefore, conducting a preliminary study to identify students' needs and readiness is advisable before implementing e-worksheets. Finally, it is also necessary to consider factors of student motivation and engagement, as the interactivity of e-worksheets may not always be appealing to all students. Considering these obstacles, further research can be comprehensively designed to ensure more accurate and applicable results.

Based on the potential obstacles identified, teachers should take several steps to implement e-worksheets in their classrooms effectively. First, they should conduct a preliminary assessment to gauge students' technological literacy, background knowledge, and critical thinking skills. This will help tailor the e-worksheets to meet the diverse needs of students, ensuring that the content is accessible and engaging for all learners. Additionally, teachers should provide adequate training or support for students who may struggle with using technology, particularly in schools with limited access to digital resources. To address varying levels of student motivation and engagement, teachers can incorporate interactive and multimedia elements that cater to different learning preferences, such as videos, quizzes, or gamified activities. Furthermore, it is crucial to maintain open communication with students to gather feedback on the effectiveness of the e-worksheets and make necessary adjustments. By considering these factors, teachers can create a more inclusive and effective learning environment, maximising the benefits of e-worksheets while minimising potential challenges.

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