



Liveworksheet-Based E-LAPD to Enhance Students' Critical Thinking in Chemical Equilibrium

Nabila Aulia Ramadhani & Sukarmin*

Chemistry Department, Faculty of Mathematics and Natural Science, Universitas Negeri Surabaya,
Jl. Ketintang, Ketintang, Kec. Gayungan, Surabaya, Indonesia

*Corresponding Author e-mail: sukarmin@unesa.ac.id

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Abstract

This study focuses on developing interactive multimedia in the form of a Liveworksheet-based Electronic Student Activity Sheet (E-LAPD) designed to enhance students' critical thinking ability in chemical equilibrium. The research employs Thiagarajan's 4D model (Define, Design, Develop, and Disseminate), limited to the Develop stage. The study evaluates the E-LAPD's validity, practicality, and effectiveness. Validity was assessed by three experts using a Likert scale through content and construct validation, with results indicating that the E-LAPD met valid criteria across all assessed aspects. Practicality was determined through quantitative descriptive analysis of student response questionnaires and activity observation sheets, demonstrating a very practical rating supported by consistently high relevant student activity percentages across three sessions. Effectiveness was measured using N-Gain scores and a paired-sample t-test comparing pretest and posttest critical thinking scores, which revealed statistically significant improvement with N-Gain scores ranging across moderate-to-high categories. These outcomes collectively affirm that the Liveworksheet-based E-LAPD is a valid, practical, and effective learning tool. The guided inquiry approach integrated into the E-LAPD promotes active student engagement and fosters the development of critical thinking across all indicators, underscoring its strong potential as an innovative instructional medium for advancing higher-order thinking skills in chemistry education.

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INTRODUCTION

Education stands as one of the most fundamental human necessities and serves as a key benchmark in measuring a nation's level of progress and development. As part of its commitment to enhancing the overall quality of education across the country, the Indonesian government has introduced and implemented the Merdeka Curriculum, an educational framework designed to foster active and student-centered learning, strengthen digital literacy skills, and shape the character of students in accordance with Pancasila values. Furthermore, this curriculum aligns closely with Sustainable Development Goal (SDGs) 4, which advocates for the provision of equitable, inclusive, and high-quality education for all individuals regardless of background.

Within this broader educational landscape, chemistry emerges as one of the subject areas that demands greater focus and more serious attention

Chemistry is a core branch of natural science that plays a vital role in understanding natural phenomena at the atomic and molecular level. However, its abstract nature, involving conceptual complexity, symbolic representation, and processes invisible to the naked eye, makes it among the most difficult subjects for senior high school students (Sanga & Wangdra, 2023). This is reflected in findings by Aisyah et al. (2021), where the majority of students perceived chemistry as difficult and unengaging, leading to poor conceptual understanding. Consistent with this, preliminary research at SMAN 16 Surabaya

confirmed that most students share this perception, with the primary contributing factor being low student engagement during learning.

Among chemistry topics, chemical equilibrium stands out as particularly challenging. Its complexity arises from the invisibility of equilibrium processes, the demand for strong foundational knowledge, and the precision required in mathematical reasoning. Preliminary findings at SMAN 16 Surabaya identified chemical equilibrium as the most difficult topic for a substantial portion of students. This aligns with Indriani et al. (2017), who found that students' understanding of factors influencing equilibrium shifts was notably weaker compared to other subtopics. Teacher interviews further revealed that students require considerably more time to comprehend equilibrium shifts, especially in contexts involving the addition or removal of reaction components.

Critical thinking ability has become one of the primary competencies that students must possess in order to navigate the wide array of challenges emerging in the twenty-first century. This era is broadly recognized as a knowledge-driven age centered around the rapid advancement of the Fourth Industrial Revolution, where the mere mastery of knowledge is no longer considered sufficient unless it is accompanied by relevant and well-developed skills (Rahmah, 2023).

The 4C framework, encompassing critical thinking, communication, collaboration, and creativity, reflects the skills required for success in a knowledge-driven era shaped by the Fourth Industrial Revolution (Yusliani et al., 2019). This is further reinforced by the Regulation of the Minister of Education and Culture Number 20 of 2016, which mandates that senior high school students demonstrate critical, creative, and collaborative thinking through a scientific approach (Kemendikbud, 2016). Critical thinking encompasses six core indicators: interpretation, analysis, evaluation, inference, explanation, and self-regulation. (Facione, 2015).

Despite its recognized importance, critical thinking ability remains underdeveloped among senior high school students. Hasanah et al. (2023) reported that nearly two-thirds of students demonstrated low critical thinking ability. This gap is especially pronounced in chemical equilibrium learning, a subject that inherently

demands higher-order reasoning Yanuarti & Azizah (2013).

Pre-research data at SMAN 16 Surabaya confirmed that students had not been adequately trained to apply critical thinking within this topic, with low achievement across all critical thinking indicators. Compounding this issue, the instructional media commonly used in schools, such as PowerPoint presentations, printed worksheets, and textbooks, were perceived by students as insufficiently engaging and unable to visualize dynamic equilibrium processes interactively. These dual gaps in thinking skill development and media quality signal a clear need for an instructional solution that is both conceptually rigorous and pedagogically stimulating (Azziah, 2013).

One of the alternative solutions that can be implemented to address this issue is the development of interactive multimedia as an instructional learning medium. Interactive multimedia itself refers to a combination of various media elements, encompassing text, images, audio, video, and animation, which function collectively as a unified and integrated whole while enabling two-way communication to take place between the user and the computer system (Holida et al., 2014).

The primary advantage of interactive multimedia lies in its remarkable capacity to present macroscopic, microscopic, and symbolic chemical representations in a manner that is concrete, well-integrated, and visually engaging, achieved through the thoughtful incorporation of images, videos, and particle animations (Marjuni & Harun, 2019).

To address this, the present study develops an Electronic Student Activity Sheet (E-LAPD) using the Liveworksheet platform as interactive multimedia for learning chemical equilibrium, specifically focusing on the subtopic of factors affecting equilibrium shifts. Liveworksheet was selected for its capacity to support interactive, two-way learning experiences and its existing familiarity among students based on pre-research findings. By integrating guided inquiry into an interactive digital format, this E-LAPD is designed to actively engage students and systematically cultivate their critical thinking ability across all indicators, offering a meaningful and innovative contribution to chemistry education at the senior high school level.

METHOD

Research Design

The research design employed in this study is research and development. This research and development project aims to produce an interactive multimedia product specifically designed to enhance students' critical thinking abilities in relation to the topic of chemical equilibrium. The study adopts the 4D research and development model introduced by Thiagarajan et al. (1974) which is structured around four sequential stages, namely defining, designing, developing, and disseminating. However, the scope of this study is limited exclusively to the development stage. The experimental design applied in this research is a limited experiment utilizing a one-group pretest-posttest design, which serves as the basis for determining the extent of changes observed in students' critical thinking abilities throughout the course of the study.

Research Subject

The participants involved in this study were eleventh-grade students enrolled at SMAN 16 Surabaya who were undertaking the second semester of the 2025/2026 academic year. The research was carried out within a single classroom setting comprising a total of 36 students. The selection of these participants was based on careful consideration of the diversity in their critical thinking ability levels as well as the varying degrees of conceptual understanding that each student possessed with respect to the subject matter of chemical equilibrium.

Development Procedure

Define Stage

The define stage represents a phase that is deliberately structured to identify and clarify the various existing needs, while simultaneously gathering relevant information pertaining to the elements that will be developed within the product. This stage is also commonly referred to as needs analysis, which encompasses a comprehensive range of analytical activities, spanning from front-end analysis through to the analysis of learners, task analysis, concept analysis, and ultimately the formulation of the intended learning objectives. In its implementation, data collection during this stage was carried out through the use of questionnaire instruments as the primary tool for conducting the needs analysis. The outcomes derived from this stage subsequently serve as the foundational

basis for efforts aimed at enhancing students' critical thinking abilities, determining the subtopics associated with the subject matter of chemical equilibrium, as well as establishing the learning objectives that are sought to be accomplished throughout the study.

Design Stage

The design phase involves determining the concept to be adopted and creating a prototype or mock-up of the product. The design phase aims to develop an interactive multimedia resource specifically an E-LAPD to enhance students' critical thinking skills using the Liveworksheet online platform. During this phase, the design is adapted to the results of the definition phase. This phase includes test development, media selection, format selection, and initial design. The initial design of the materials, once completed, is called "Draft I"; it is then reviewed and validated during the development phase before limited testing is conducted.

Develop Stage

At this stage, the developed product will be validated by several experts, followed by product testing. The testing phase is conducted once the validation process is complete. The testing process consists of several stages: product validity testing by several experts, followed by limited testing. Validation is conducted by three experts; any feedback or suggestions from the validators are used to revise the teaching materials. Subsequently, the limited trial was conducted at SMAN 16 Surabaya over 3 sessions involving 36 students. The class was selected because it was studying the topic of chemical equilibrium and comprised students with varying levels of critical thinking skills.

Data Collection and Analysis

Development research can be considered valid if it meets three criteria: validity, practicality, and effectiveness (Plomp & Nieveen, 2007).

Validity

The validity of the E-LAPD was assessed by three expert validators — two chemistry lecturers and one chemistry teacher — covering content and construct aspects using a Likert scale (1–5). The data were analyzed by determining the mode, or median when scores varied, with a minimum valid threshold of 4. Media scoring below this threshold were revised and resubmitted for revalidation (Haladyna & Rodriguez, 2013).

Practically

Practicality was measured through data obtained from student response questionnaires and student activity observation sheets. The student response questionnaire contained both positively and negatively worded statements, and therefore the data generated from the questionnaire were analyzed by employing the Guttman scale as the analytical framework. The criteria utilized within the Guttman scale are presented in greater detail in Table 2 below.

Table 1. Scale Guttman

Statement	Score	Criteria
Positive	Yes	1
	No	0
Negative	Yes	0
	No	1

Source: Riduwan (2016)

The survey response data will be calculated using the following formula:

$$\% \text{ practicality} = \frac{\text{score obtained}}{\text{maximum score}} \times 100\%$$

Furthermore, the results obtained from the student activity observation sheets encompass the various activities carried out by students throughout the learning process that utilized E-LAPD as an instructional medium aimed at enhancing critical thinking skills in relation to the topic of chemical equilibrium. The data gathered from the student observation sheets were subsequently analyzed through quantitative descriptive analysis by calculating the percentage of student activities using the designated formula:

$$\% \text{ student activity} = \frac{\text{frequency of observed activities}}{\text{total frequency of activities}} \times 100\%$$

The percentage results from the student response questionnaire and observations of student activities were interpreted according to the practicality score criteria in the following Table 3.

Table 2. Practically Interpretation Criteria

Percentage Score (%)	Criteria
0 – 20	Very Impractical
21 – 40	Impractical
41 – 60	Fairly Impractical
61 – 80	Practical
81 – 100	Very Practical

Source: Riduwan (2016)

The percentage results derived from both the student response questionnaires and the student activity observations were interpreted based on the practicality score criteria outlined in the following table. Drawing from these established

criteria, the E-LAPD concerning chemical equilibrium that was specifically designed to enhance students' critical thinking abilities is considered to meet the standard of practicality if the results obtained from both the student response questionnaires and the student activity observations yield a percentage value of $\geq 61\%$, or fall within the category classified as practical and highly practical (Riduwan, 2016).

Effectiveness

Effectiveness can be assessed through the results of both the pretest and posttest administered in relation to students' critical thinking abilities and their conceptual understanding of chemical equilibrium. The pretest and posttest results pertaining to critical thinking abilities were analyzed using the N-gain formula in order to determine the extent of improvement achieved in students' critical thinking ability over the course of the study. In addition, the data were further examined through the application of the Shapiro-Wilk test to evaluate whether the distribution of the data met the assumption of normality. If the results of the normality test ($p > 0.05$) indicate a normal distribution, a Paired Sample t-test can be performed. However, if the data are not normally distributed, a non-parametric test such as the Wilcoxon test is used to determine whether the improvement in students' critical thinking ability is statistically significant.

The formula for N-gain is as follows.

$$N - \text{Gain} = \frac{(\text{pretest score} - \text{posttest score})}{(\text{maximum score} - \text{pretest score})}$$

The N-Gain scores obtained are interpreted according to the following criteria:

Table 3. N-Gain Criteria

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

According to the established N-Gain criteria, the E-LAPD on Chemical Equilibrium that was specifically developed to strengthen students' critical thinking abilities is regarded as effective provided that the N-Gain score achieved falls within the range of $0.3 \leq (g) < 0.7$, which corresponds to the moderate category, or reaches a value of $(g) \geq 0.7$, which is classified under the high category.

The normality test was performed using the Shapiro-Wilk test in SPSS. The data are

considered normally distributed if the significance value is > 0.05 . The decision criteria are presented in Table 5.

Table 4. Shapiro-Wilk Normality Test Decision Criteria

Significance Value (p-value)	Decision	Interpretation
$p < 0,05$	Reject H_1	data are not normally distributed
$p > 0,05$	Accept H_1	data are normally distributed

Source: Sugiyono (2019)

In the event that the data are found to follow a normal distribution, the analytical process will continue with the application of a paired sample t-test to evaluate whether a statistically significant improvement has occurred in students' critical thinking ability. The criteria upon which the decision will be based are detailed in Table 6.

Table 5. Paired-Sample t-Test Decision Criteria

p-value	Decision	Interpretation
$p < 0,05$	Accept H_1	Posttest scores $>$ pretest scores; there was a significant improvement in students' critical thinking ability
$p > 0,05$	Reject H_1	Posttest scores $\leq$ pretest scores; there was no significant improvement in students' critical thinking ability

Source: Sugiyono (2019)

In the event that the data do not conform to a normal distribution, the analysis will be carried out by employing the Wilcoxon signed-rank test, which is a nonparametric statistical test. The decision criteria established based on a significance level of $\alpha = 0.05$ are presented in Table 7.

The pretest and posttest data on chemical equilibrium knowledge were analyzed based on the Learning Objective Achievement Criteria (KKTP). The KKTP was used because it aligns with the Merdeka Curriculum approach, which assesses the achievement of learning objectives. The formula used is as follows:

$$\text{Individual Completeness} = \frac{(\text{Total Score Obtained})}{(\text{maximum score})} \times 100\%$$

Based on this percentage, students are considered to have met the KKTP if they score ≥ 75 .

Table 6. Wilcoxon Test Decision Criteria

p-value	Decision	Interpretation
$p < 0,05$	Accept H_1	there is a difference between the median critical thinking ability of students before and after learning with the E-LAPD
$p \geq 0,05$	Reject H_1	there is no difference between the median critical thinking ability of students before and after learning with the E-LAPD

Source: Sugiyono (2019)

RESULTS AND DISCUSSION

Define Stage

The define stage was carried out by distributing questionnaires to twelfth-grade students who had previously studied the topic of chemical equilibrium, as well as by conducting interviews with chemistry teachers at SMAN 16 Surabaya. This stage encompasses five distinct components, namely front-end analysis, learner analysis, concept analysis, task analysis, and the formulation of learning objectives. The front-end analysis was conducted through direct observation of the chemistry learning process taking place at SMAN 16 Surabaya. Observations involved interviewing chemistry teachers and having students complete questionnaires. Student analysis covers students' cognitive development and academic abilities. Concept analysis is presented in the form of a concept map that assists students in grasping an overall picture of chemical equilibrium, particularly the section addressing the factors that influence the shift in equilibrium direction. Task analysis involves the identification and design of assignments given to students throughout the learning process with the aim of developing their critical thinking ability. Finally, learning objectives are formulated in alignment with the learning outcomes for the chemical equilibrium material.

Design Stage

The design phase is intended to develop interactive multimedia, specifically the E-LAPD, as a means of enhancing students' critical thinking ability by utilizing the online platform Liveworksheet. This phase encompasses several key activities, including the development of

question items, the selection of appropriate media, the determination of suitable formats, as

well as the preparation of the initial draft (Draft I) with layout as shown in Figure 1..

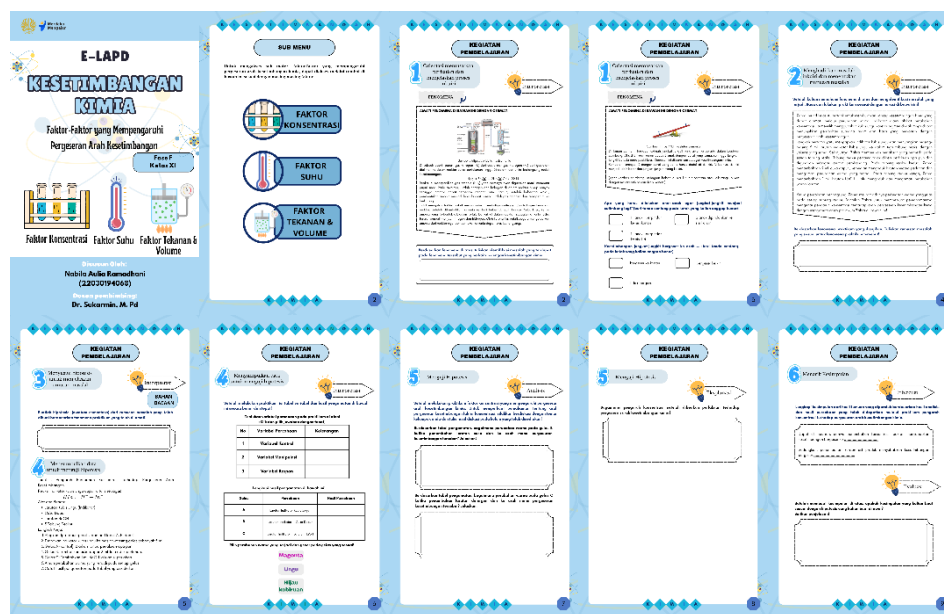


Figure 1. E-LAPD

The main E-LAPD cover differs from the covers for each E-LAPD factor because the images on the cover represent each factor. Learning activities in E-LAPD use a guided inquiry learning model, so the content of E-LAPD is aligned with the phases of guided inquiry, ranging from Phase 1 to Phase 6. Additionally, there are interactive features, including the ability to click on reading materials to be directed directly to a video containing the content, and the ability to swipe through answer options.

Develop Stage Validity

The validation was conducted by three experts: two chemistry lecturers from Surabaya State University and one chemistry teacher from SMAN 16 Surabaya. The validation phase aimed to evaluate the developed E-LAPD based on content and construct validity. Regarding content validity, the aspects evaluated included the criteria for the E-LAPD's alignment with the subject matter, the alignment of the content included in the E-LAPD, and the alignment of the E-LAPD with indicators of critical thinking skills. The results showed that the E-LAPD's alignment with the subject matter received a mode score of 4, meeting the "good" criterion. Regarding the alignment of the content included in the developed E-LAPD, it received a mode score of 5 with a "very good" rating. Regarding the alignment of the E-LAPD with critical thinking

ability indicators, it received a mode score of 5 with a "very good" rating. Furthermore, construct validity was assessed in terms of language, presentation, and graphics in the developed E-LAPD medium, with the validation results for each aspect yielding a mode score of 4 under the "good" criterion. Thus, the developed E-LAPD was deemed valid. After validation, the E-LAPD was then pilot-tested at SMAN 16 Surabaya over 3 sessions or 5 class periods.

Practically

The practicality was determined based on the results of the student response questionnaire, supported by observations of student activities during lessons using the developed E-LAPD. The student response questionnaire was administered after students participated in lessons using the developed E-LAPD. The questionnaire was completed by 36 students, yielding an average score of 92.1% in the "very practical" category. Student activity observations were conducted by 6 observers, with each observer observing student activities in 1 group consisting of 6 students. The results of the student activity observations showed that in the first, second, and third sessions, the percentages of relevant activities were 94.2%, 92.5%, and 94.2%, respectively, which were more dominant than irrelevant activities. This indicates that student activities during the trial of the Liveworksheet-based E-LAPD were carried out well and supported the practicality of

the developed product. Thus, the developed E-LAPD is deemed practical.

Effectiveness

The effectiveness of the Liveworksheet-based E-LAPD in enhancing students' critical thinking ability regarding chemical equilibrium was measured through pretest and posttest scores on both critical thinking ability and knowledge of chemical equilibrium, utilizing a test instrument comprising 15 items, with three items allocated per indicator. The indicators employed in this study include interpretation, analysis, explanation, inference, and evaluation (Facione, 2015). Additionally, the pretest and posttest items concerning knowledge of chemical equilibrium consisted of 6 questions with varying levels of cognitive demand.

First, the pretest and posttest results pertaining to critical thinking ability were examined through a normality test. The outcomes of the Shapiro-Wilk normality test revealed significance values of 0.146 for the pretest and

0.660 for the posttest, both of which exceeded the threshold of 0.05, thereby indicating that the data followed a normal distribution.

Subsequently, a paired sample t-test was conducted, yielding a p-value of less than 0.001, which led to the acceptance of H1, confirming that a statistically significant difference existed between the pretest and posttest results. This finding substantiates that the Liveworksheet-based E-LAPD is effective in improving students' critical thinking ability.

Furthermore, the pretest and posttest results for critical thinking ability were analyzed using the N-Gain formula to determine the degree of improvement in critical thinking ability based on both the overall scores and individual indicators. Critical thinking ability is considered to have improved when an N-Gain score of $(g) \geq 0.30$ is obtained, which falls within the moderate and high categories (Hake, 1998). The N-Gain test results for the overall pretest and posttest scores are presented in Table 8.

Table 7. N-Gain Scores for Students Critical Thinking Ability on the Pretest and Posttest

No.	Student	Pretest	Posttest	N- Gain	Criteria
1.	ALI	40	85	0,75	High
2.	ANR	48	82	0,65	Medium
3.	AIZ	27	65	0,52	Medium
4.	AP	38	88	0,81	High
5.	ARN	63	80	0,46	Medium
6.	ANLQ	28	82	0,75	High
7.	ACR	33	83	0,75	High
8.	AYU	43	80	0,65	Medium
9.	AZPH	40	78	0,63	Medium
10.	AAG	68	92	0,75	High
11.	CAAR	77	93	0,70	High
12.	CF	38	75	0,60	Medium
13.	DP	27	75	0,66	Medium
14.	DASF	55	80	0,56	Medium
15.	DSM	37	78	0,65	Medium
16.	FN	13	75	0,71	High
17.	IDGNN	35	73	0,58	Medium
18.	IW	40	90	0,83	High
19.	IN	27	95	0,93	High
20.	KAN	40	73	0,55	Medium
21.	LDK	27	80	0,73	High
22.	MEP	22	75	0,68	Medium
23.	MPS	37	73	0,57	Medium
24.	MSA	25	68	0,57	Medium
25.	NQA	30	70	0,57	Medium
26.	RARS	42	92	0,86	High
27.	SFD	40	78	0,63	Medium
28.	SMAP	62	82	0,53	Medium
29.	MRS	10	87	0,86	High
30.	SKV	45	90	0,82	High
31.	SAP	18	72	0,66	Medium

No.	Student	Pretest	Posttest	N- Gain	Criteria
32.	SNA	35	80	0,69	Medium
33.	TKN	37	83	0,73	High
34.	TS	63	87	0,65	Medium
35.	ZDI	28	70	0,58	Medium
36.	ZAS	47	78	0,58	Medium

Based on these results, 14 students achieved N-Gain scores in the range of 0.70–0.93 (high category), and 22 students achieved N-Gain scores in the range of 0.46–0.69 (moderate category). To assess improvements in each critical thinking indicator, N-Gain tests were also conducted for each indicator, with the results presented in the following Table 9.

Table 8. N-Gain Score Average Percentage Critical Thinking Ability Indicator

Indicator	Pre-test	Post-test	N-Gain	Criteria
Interpretation	63,3	85,8	0,71	High
Analysis	38,3	73,3	0,61	Medium
Explanation	35,0	78,3	0,67	Medium
Inference	30,8	75,8	0,66	Medium
Evaluation	28,3	80,8	0,76	High

The N-gain scores for each critical thinking indicator showed a moderate increase for the Analysis, Explanation, and Inference indicators. Meanwhile, the Interpretation and Evaluation indicators showed a significant increase.

The indicator showing the greatest improvement, reaching the high category, was interpretation the ability to understand, explain, and make sense of information or data (Facione, 2015). This indicator encompassed sub-indicators including formulating research questions, developing hypotheses, and identifying experimental variables. The pronounced improvement in this indicator can be attributed to the contextual problem-based structure of the E-LAPD, which systematically required students to process and make meaning of information before arriving at solutions. This aligns with Ariyana et al. (2018), who assert that HOTS-based learning facilitates independent understanding through problem identification, question formulation, and hypothesis development. Critically, this suggests that when students are consistently exposed to structured, inquiry-driven tasks that demand active sense-making, foundational critical thinking skills such as interpretation are among the first to develop, as they serve as the cognitive entry point for all subsequent reasoning processes.

The evaluation indicator similarly demonstrated significant improvement. Evaluation involves verifying the validity and relevance of data in relation to supporting arguments (Facione, 2015), operationalized here through the sub-indicator of comparing experimental data against established scientific concepts. The improvement in this indicator reflects students' growing capacity to move beyond data collection toward critically interrogating the meaning and reliability of their findings. This is a particularly noteworthy outcome, as evaluation is widely regarded as a higher-order critical thinking skill that students often struggle to develop without deliberate instructional scaffolding.

The E-LAPD's design, which required students to reconcile their observations with scientific principles, appears to have provided precisely this scaffolding. In contrast, the indicators of analysis, explanation, and inference showed moderate improvement, a pattern that warrants deeper examination.

While students demonstrated progress in analyzing equilibrium shifts under varying conditions, the moderate gain suggests that analytical reasoning, particularly when applied to abstract, invisible chemical processes remains cognitively demanding even within a structured inquiry framework. Similarly, although explanation skills, encompassing the ability to communicate reasoning in a logical and structured manner, showed development, the moderate gain may reflect the inherent difficulty students face in articulating scientific reasoning with precision, especially at the senior high school level.

For inference, while guided inquiry stages supported students in drawing conclusions from experimental data regarding the effects of concentration, temperature, pressure, and volume on equilibrium shifts, the moderate improvement indicates that the ability to independently synthesize evidence into well-grounded conclusions requires sustained practice

beyond a single instructional cycle. Taken together, these moderate gains suggest that while the E-LAPD effectively initiates the development of higher-order thinking, extended exposure and iterative practice may be necessary to elevate these indicators to the high category.

Regarding chemical equilibrium conceptual understanding, results from the knowledge test revealed an important nuance. While the majority of students had already achieved mastery on the pretest, reflecting a substantial degree of prior knowledge, seven students had not yet met the mastery threshold. Notably, following engagement with the Liveworksheet-based E-LAPD, all students — including those seven — achieved posttest mastery with scores ranging from 80 to 100. This outcome is significant for two reasons. First, it demonstrates the E-LAPD's capacity not only to reinforce existing understanding but also to address and remediate conceptual gaps among lower-achieving students. Second, the universal achievement of mastery across a heterogeneous group of learners suggests that the interactive and self-paced nature of the Liveworksheet platform may support differentiated learning in ways that conventional instructional media cannot, allowing students with varying prior knowledge levels to progress toward conceptual mastery through the same medium.

CONCLUSION

Based on the findings of this study, the Liveworksheet-based E-LAPD developed to enhance students' critical thinking ability in chemical equilibrium is valid, practical, and effective, as evaluated through the framework proposed by Nieveen & Plompt (2007).

In terms of validity, the E-LAPD met valid criteria across both content and construct aspects, with a mode score of 4, categorized as "good." Regarding practicality, student response questionnaires yielded a rating of 92.1%, classified as "very practical," supported by consistently high relevant student activity percentages across all three learning sessions, all falling under the "very good" category. In terms of effectiveness, N-Gain scores ranged from 0.46 to 0.93, indicating moderate-to-high improvement in critical thinking ability across all students. This was further confirmed by a paired-sample t-test ($p < 0.001$), which demonstrated a statistically

significant difference between pretest and posttest scores. Additionally, all students successfully achieved passing scores on the chemical equilibrium knowledge test.

Collectively, these results affirm that the Liveworksheet-based E-LAPD, through its integration of guided inquiry, effectively fosters active student engagement and systematically cultivates critical thinking ability in chemical equilibrium learning.

RECOMMENDATION

Future researchers are encouraged to proceed to the dissemination stage by implementing the E-LAPD across multiple schools with larger and more diverse student populations to assess its broader applicability and generalizability. In addition, the critical thinking indicator of self-regulation should be incorporated into subsequent versions of the E-LAPD by designing specific activity prompts that require students to reflect on and evaluate their own reasoning process. Further research may also explore the application of this E-LAPD approach to other chemical equilibrium subtopics, such as the equilibrium constant or reaction quotient, or extend it to related chemistry topics such as acid-base equilibrium, to determine whether comparable improvements in critical thinking ability can be achieved across different conceptual contexts. Longitudinal studies examining the sustainability of critical thinking gains over time would also provide valuable insight into the long-term impact of this instructional medium.

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