Effectiveness of E-book thermodynamics based on STEM discovery learning assisted with virtual laboratory simulation to improve high school students' critical thinking

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This study aims to determine the effectiveness of the Thermodynamics E-Book assisted by a virtual lab with a STEM approach that is implemented for students and operated through student devices. The research model used is a quasi-experiment with a one-group pre-test post-test design. This study uses one experimental class and one control class that are differentiated by treatment in learning activities. Based on the analysis, it was found that the problem of developing students' critical thinking was still lacking. The results showed significant results in improving critical thinking skills in the experimental class using the Thermodynamics E-Book assisted by the virtual lab with a STEM approach. Data from pre-test and post-test results have been tested and proven to be normally distributed and homogeneous with a significance value greater than 0.05. The N-gain score in the experimental class was 0.720 and in the control class was 0.699. The use of a virtual lab-assisted Thermodynamics E-Book with a STEM approach is able to contribute to improving critical thinking skills.

Keywords: Learning media; E-book; thermodynamics; critical thinking.

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1. Introduction

The challenge of education to continue to adapt to the times requires special attention and transformation in the world of education. 21st-century skills are seen as a form of skills needed for future generations to be able to compete globally [1,2]. 21st-century competencies are generally developed by incorporating abilities such as self-efficacy, collaboration, critical thinking, and awareness of technical nature, for example, in information and communication technology [3]. The 21st century skills and the cognitive levels of Bloom's taxonomy coexist and support each other. Learning and initiative skills include four sub-skills: critical thinking and problem-solving, innovation and creativity, communication, and collaboration. Critical thinking and problem solving can lead to creativity and innovation, and Bloom's taxonomy includes innovative thinking [4]. Further examination of 21st-century skills strongly supports learners being able to think critically, learn independently, and collaborate.

Critical thinking is very important for learners in the 21st century because the world today is full of information that must be analyzed and understood carefully. With critical thinking skills, learners can distinguish between true and false information, solve problems more effectively, make sound decisions, and adapt to rapid changes [5,6]. Critical thinking skills are also needed in order to form learners who are sensitive to change and create lifelong learners. This indicates that critical thinking is very important because it can change the mindset in life [7,8]. However, in reality there is still a problem, namely the low critical thinking skills of students [9,10]. This becomes an obstacle if they are faced with problems that require critical thinking. The importance of critical thinking skills seems to be a challenge for education today. Critical thinking skills are closely related to higher-order thinking skills. Awareness of the importance of critical thinking makes it easier for students to control their goals and know their personality [11]. Existing assessment instruments in schools only measure low-level thinking skills [12,13]. This proves that there is an inability of educators to construct and create a test instrument that measures based on appropriate indicators for critical thinking skills. So it is important for educators to develop and strive to improve critical thinking skills. One of them is by utilizing technology to assist students in observing and evaluating a problem.

One of the utilizations of technology in the learning process that is practical, easy, and relevant to the current times is by implementing teaching materials using E-Books [14]. E-Books have a higher interactive level than ordinary textbooks [15]. The use of E-Books in learning is a learning medium to improve learning strategies and support students' metacognition skills [16]. The existence of E-Books provides space for text, images, animations, simulations and videos to contribute to the learning process of learners [17]. This completeness supports the critical thinking process of learners through observation. In addition, the integration of videos, virtual laboratories and additional information links in E-Books will make learning resources complex and interesting. STEM (Science, Technology, Engineering, Mathematics) is a learning approach that links real-life events with science, technology, engineering and mathematics majors

and helps develop skills needed globally in the 21st-century [18,19]. The implementation of the STEM learning approach in E-Books will give life to E-Books to be more involved in the learning process. Various countries have integrated STEM into the curriculum as a means of meaningful learning [20,21]. Based on Harris de Bruin research, E-Books integrated with the STEM approach are able to shape students to be able to have critical thinking, collaboration, creative and communication skills [22]. The STEM approach is able to generate concepts and critical thinking processes needed in the 21st century [22]. This is reinforced by research findings that show that critical, creative, and innovative thinking changes with the STEM approach [23].

The use of E-Books supports physics learning which really needs media to explain physical phenomena. This requires the role of a virtual laboratory linked to the E-Book so that students can observe, analyze and explore so that they find concepts [24]. In thermodynamic material, the role of E-Books with a STEM approach and integrated with virtual labs is needed. The limitation of the human sense of vision in observing particle behavior is one of the inhibiting factors in learning the basic concepts of thermodynamics and ideal gas behavior. We think that the implementation of the E-Book product will certainly help students in a structured manner to critically conclude the relationship between changes in pressure, volume and temperature in gas particles. The STEM-integrated interactive E-Book design was developed and tested in a physics class. The development product in the form of an E-Book with a STEM Discovery Learning approach assisted by a virtual lab simulation is designed to improve students' critical thinking skills. The availability of these products needs to be tested for effectiveness through field trials. Therefore, this study aims to evaluate the effectiveness of the Thermodynamics E-Book with the Discovery Learning model STEM approach in improving students' critical thinking skills.

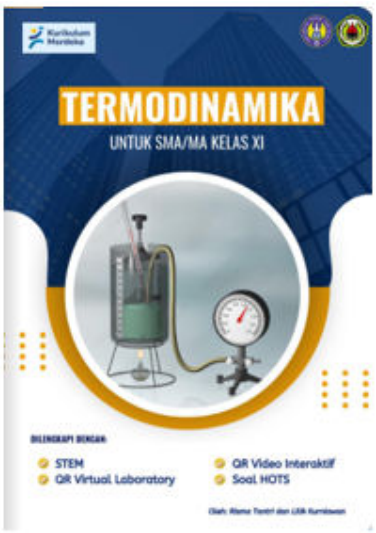

FIGURE 1. Display E-book thermodynamics cover.

FIGURE 2. Data collection and processing on E-book assisted by a virtual laboratory.

2. Method

E-Book products in this study can be seen at URL: `https://heyzine.com/flip-book/3d059914b6.html`. The E-Book design was created using the Canva tool to produce a visually appealing and up-to-date template design. It was then further modified using Microsoft Office Word. The cover design that has been developed can be seen in Fig. 1. This E-Book was launched using heyzine flip-book in HTML format, which allows students to easily access it without seeing the difference in operating systems on each device. In addition, by utilizing heyzine the developed E-Book has a flipping effect on the physics E-Book. This prevents learners from becoming bored and encourages their motivation to learn about physics. Previous research also states that the use of interactive e-books can encourage learners' motivation to be actively involved and the amount of effort they put into exploring procedural and conceptual knowledge [25,26]. The development carried out equips the E-Book with apperceptions, *i.e.*, videos explaining the experiments that will be carried out in the virtual laboratory.

Figure 2 displays the QR Code design and video tutorial for the thermodynamic practicum. Learners can access the virtual laboratory by clicking on the icon or scanning the QR. The learning activity facilitates learners to perform data collection syntax to be processed and analyzed. The results of these activities build learners' knowledge about the relationship between Pressure P, Temperature T, and Volume V.

Figure 3 shows a virtual laboratory that facilitates students in learning activities in the classroom. The virtual laboratory included in the E-book uses PhET. The video tutorial included will also guide students in understanding the experimental scheme on thermodynamic material. The use of virtual laboratories increases knowledge and becomes an innovative learning strategy in the present [27]. Research studies also prove that technology integration has a significant impact not only on learners, but also on teachers' cognitive ability to innovate in learning [28].

Apart from using the guidance from the video, learners can explore by changing the variables that will be made constant in the experiment. The width of the particle tank and the number of collisions that occur on the particles can be

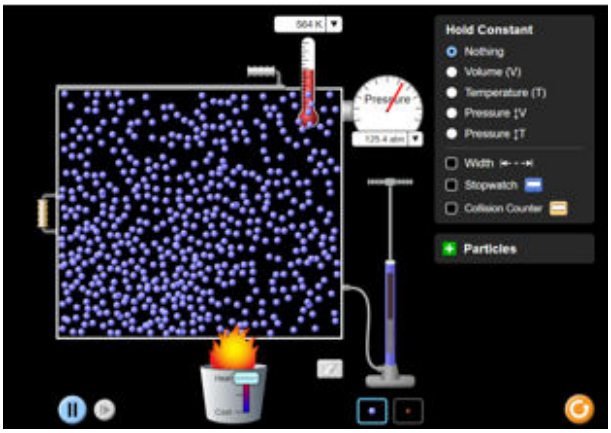

FIGURE 3. Data collection and processing on E-book assisted by a virtual laboratory.

TABLE I. Design one-group pretest-posttest design.

Class	Pre-test	Treatment	Post-test
Experiment	O_1	X_1	O_2
Control	O_1	X_2	O_2

observed by students directly in the virtual laboratory. In this process, students will be trained to think critically about the response of particle behavior to the treatment given.

This research is a quasi-experiment with a one-group pretest-posttest design and was conducted from April to May 2024 in Yogyakarta. The total sample consisted of 72 grade XI students from two phase F classes. The two classes will be divided into experimental and control classes to see the effectiveness of using E-Books with a STEM approach. Sampling was conducted using the randomized cluster sampling method. Therefore, the sample of this study was taken randomly from the population, so that each cluster had the same opportunity to be selected. Table I shows the experimental and control class design for the field trial.

Description: O_1 = Data results of evaluation of critical thinking before treatment, O_2 = Data results of assessment of critical thinking skills after treatment. X_1 = Learning using with a E-Book with STEM approach, X_2 = Learning using conventional learning models.

Data collection uses test instruments that display critical thinking indicators, namely: (1) Providing arguments based on problem. (2) Identifying problems of facts and hypotheses, and (3) making conclusions. This test instrument measures the improvement of critical thinking skills as a result of using the STEM-based thermodynamics E-Book assisted by a Virtual Laboratory Simulation. The critical thinking test instrument was validated by two expert validators who are physics education lecturers. The assessment of the test instrument includes content feasibility, language feasibility, and question construction. The experts have validated the items on the test instrument. The validation results based on expert statements and decisions concluded that the test instrument was feasible to use to measure critical thinking skills.

TABLE II. N-gain Categorization.

Interval	Category
0.70 < N-gain	High
0.30 ≤ N-gain ≤ 0.70	Medium
N-gain < 0.30	Low

$$N - Gain = \frac{(S_{\text{post}} - S_{\text{pre}})}{(S_{\max} - S_{\text{pre}})}. \quad (1)$$

where S_{post} = posttest values for each student, S_{pre} = pretest values for each student, $S_{\max}$ = maximum value.

The result of the calculation of the gain score (N-gain) can be categorized according to the criteria listed in Table II.

The N-Gain value refers to the category of the impact of critical thinking skills from the use of E-Books which consists of three categories, namely high, medium, and low. Before the N-Gain test was conducted with the help of Microsoft Excel.

3. Result and discussion

For data analysis, inferential analysis is used to determine the impact of flip-books by comparing students' pretest and posttest values. The N-Gain test Eq. (1) is used to evaluate the result. The findings of this study are presented through the assessment of pre-test and posttest scores using a test tool that includes indicators of critical thinking skills. Figure 4 displays average students' pre-test and post-test scores for the experimental and control classes.

The increase in post-test scores obtained by students is clearly visible through the bar chart. The bar chart in Fig. 4 provides reinforcing information that the posttest score has increased significantly compared to the pretest score. Table III shows the normality test based on the Shapiro-Wilk Test. The Shapiro-Wilk Test is used because the data for each class has a number smaller than 50.

Based on the normality data according to the Shapiro-Wilk Test, all of these data have a significance value that exceeds 0.05, so it can be concluded that the pretest and posttest data on students' critical thinking are normally distributed. Likewise, with data homogeneity testing, the pre-test and posttest scores of students' critical thinking skills

TABLE III. Shapiro-Wilk normality test results of pretest and posttest data.

Class	PreTest		PostTest		N
	Stat.	Sig.	Stat.	Sig.	
Experiment	0.941	0.055	0.948	0.90	36
Control	0.943	0.062	0.949	0.95	36

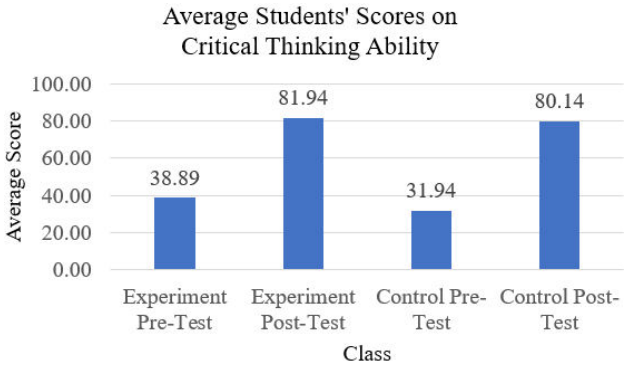

FIGURE 4. Average students' scores on critical thinking ability.

TABLE IV. Homogeneity test results Levene's test pre-test and posttest data.

Class	Levene's Test		N
	Levene Statistic	Sig.	
Experiment	2.826	0.097	36
Control	0.357	0.522	36

TABLE V. Overall N-gain result.

Class	Result	
	N-Gain Score	Category
Experiment	0.720	High
Control	0.699	Medium

were tested with Levene's Test which is used to see the similarity of the variance of the data. Based on the results of Levene's homogeneity test, it was found that the data was homogeneous with a significance value exceeding 0.05. The normality test results are presented in Table III and the homogeneity test results in Table IV.

After the critical thinking ability score is tested for normality and homogeneity, then the N-Gain test data is analyzed to determine the category of improvement and the level of effectiveness of the use of a Thermodynamics E-Book with the STEM approach. E-Book Assisted Virtual Laboratory Simulation with STEM approach is able to improve students' critical thinking skills with N-Gain category data as in Table V.

Based on the results of the analysis, it can be stated that the use of Thermodynamics E-Book assisted by Virtual Lab simulation with a STEM approach can improve students' critical thinking skills. The N-gain score in the experimental class that used the E-Book was higher than the control class that was treated with conventional learning. Learning activities in the E-Book and also virtual labs that support students to see particle phenomena in various thermodynamic processes are able to build critical thinking. This increase is supported by the findings of other studies which state that using interactive E-Books has a positive effect on students' learning activities and can even result in a significant increase in students' critical thinking [29]. The use of technology in learning can support educators in building generations in terms of skills, knowledge and expertise [30,31]. E-books are able to bridge communication between educators and students in understanding abstract material, make learning interesting, and can be integrated with various digital virtual platforms that support active learning.

4. Conclusion

This study shows that the use of a Thermodynamics E-Book with a STEM approach equipped with Virtual Laboratory Simulation for Discovery Learning has a significant and good effect on students' critical thinking skills. The N-gain score in the experimental class was 0.720 and categorized as a high increase. The control class experienced an increase in the medium category with an N-gain score of 0.699. The existence of a virtual laboratory plays a role in building conceptual knowledge that will stimulate critical thinking patterns [32]. The development and implementation of innovative teaching resources need to be continuously improved. Varied and interactive learning resources shape knowledge, critical thinking, encourage problem-solving and collaboration between students. This is the answer to 21st-century learning needs.

Apart from the positive impact of using the Thermodynamics E-Book with the STEM Discovery Learning approach with the help of Virtual Laboratory Simulations, there are still obstacles that are the limitations of this study. Internet network stability is very important when using this product so that virtual simulations can be accessed smoothly. In terms of students, their sensory experience is limited because the virtual laboratory only provides a visual experience without involving real objects that stimulate students' senses. Teachers' expertise in using the product can also be an obstacle in creating an active class and increasing critical thinking skills. So, educators need to design learning with this development product in a structured, systematic way and be able to explore the features in the E-Book. In future research, the type of material and learning model can be developed by combining various educational technologies so that it can be more interactive and able to improve the cognitive abilities of students.

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