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Evaluation of Critical Thinking Ability Through The Development of Contextual Physics Teaching Materials Assisted by Socratic Question

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Abstract

This research is one of the stages of developing contextual teaching materials assisted by Socratic questions in physics learning with the primary material of Thermodynamics. The purpose of the evaluation stage is to determine the effectiveness of applying contextual teaching materials assisted by Socratic questions on students' critical thinking skills. The development research was carried out using the ADDIE method, which consisted of the following stages: Analysis, Design, Development, Implementation, Evaluation. The implementation of teaching materials using Socratic questions with Thermodynamics material was carried out for four meetings which 64 students attended. The parameters measured in this evaluation stage are the product quality of teaching materials and students' critical thinking skills. The results showed that (1) the process of developing contextual physics teaching materials assisted by Socratic Questions had met the product quality criteria, which included validity, practicality, and effectiveness (2) there was a significant difference between students' critical thinking skills in physics using Socratic-assisted contextual teaching materials—question without product application. In addition, it was found that the profile of students' critical thinking skills in physics learning using contextual physics teaching materials products Socratic questions was higher than in learning that did not use contextual physics teaching materials assisted by Socratic questions (with critical thinking indicators consisting of giving arguments, induction, evaluating, and make decisions).

Key words: critical thinking ability, socratic question

Evaluasi Kemampuan Berpikir Kritis melalui Pengembangan Bahan Ajar Fisika Kontekstual Berbantuan Socratic Question

Abstrak

Penelitian ini merupakan salah satu tahapan dari proyek pengembangan bahan ajar kontekstual berbantuan *socratic question* pada pembelajaran fisika dengan materi utama Termodinamika. Tujuan tahap evaluasi adalah untuk mengetahui profil keefektifan penerapan bahan ajar kontekstual berbantuan

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socratic question terhadap kemampuan berpikir kritis siswa. Penelitian pengembangan yang dilakukan menggunakan metode ADDIE yang terdiri dari tahap: *Analysis-Design-Development-Implementation-Evaluation.* Implementasi bahan ajar dengan *socratic question* dengan materi Termodinamika dilakukan selama 4 pertemuan yang diikuti oleh 64 siswa. Parameter yang diukur dalam tahap evaluasi ini adalah kualitas produk bahan ajar dan kemampuan berpikir kritis siswa. Hasil penelitian menunjukkan bahwa (1) proses pengembangan bahan ajar fisika kontekstual berbantuan *socratic question* telah memenuhi kriteria kualitas produk yang meliputi validitas, kepraktisan, dan keefektifan (2) terdapat perbedaan yang signifikan antara kemampuan berpikir kritis fisika siswa yang menggunakan produk bahan ajar kontekstual berbantuan *socratic question* tanpa penerapan produk. Selain itu, ditemukan bahwa profil kemampuan berpikir kritis siswa dalam pembelajaran fisika yang menggunakan produk bahan ajar fisika kontekstual *socratic question* lebih tinggi dibandingkan dengan pembelajaran yang tidak menggunakan bahan ajar fisika kontekstual berbantuan *socratic question* (dengan indikator berpikir kritis terdiri dari memberikan argumen, induksi, mengevaluasi, dan membuat keputusan).

Kata kunci: kemampuan berpikir kritis, *socratic question*

INTRODUCTION

The implementation of meaningful physics learning can be a support for students in facing real life in society. To achieve meaningful learning, physics must emphasize higher-order thinking skills, especially critical thinking (Triwiyono, 2011). Bailin (2002) states that one of the goals of physics education is to develop students' critical thinking. So, through learning physics, students can practice thinking critically in problem-solving activities, concluding, estimating and predicting, generalizing, and thinking creatively (Ergin, 2012; Juliyanto et al., 2011)

Students' thinking skills can be developed through questions (Hidayat, 2012; Kesipudin & Hikmawati, 2009). The level and types of questions reflect the level of thinking (Deckert & Wood, 2013). Critical thinking is one component of the higher-order thinking process (Yuliati et al., 2012). Therefore, critical thinking skills can be developed through the question method.

The results of observations on learning physics in the classroom show that teachers cannot guide students continuously in solving problems by using questions. This is due to the limited allocation of learning time and many students in one class. If the guidance or instruction given by the teacher to students is reduced, then the ability to solve problems is challenging to develop and impacts students' critical thinking skills (Slezak et al., 2011).

The results of interviews with students showed that the material in thermodynamics which includes the monatomic ideal gas theory and the laws of thermodynamics, is considered an abstract material. Students also said that the material was taught through lectures and slightly related to problems and phenomena found in real life. Based on the results of interviews with teachers, information was obtained that teachers apply the lecture method when teaching thermodynamics material due to several reasons, including (1) the material is easy to learn using the lecture method; (2) thermodynamic material is presented in the form of descriptions, quick formulas, and questions on commonly used teaching materials; and (3) they have limited learning time.

Observations were also made on teaching materials and physics books used by students in school libraries, bookstores, and electronic school books. The results of observations from all sources show that the presentation of thermodynamic material is less related to problems/phenomena/applications in real life. The available teaching materials also do not support active students, as evidenced by the lack of teaching materials that provide suitable material or discussion and study of real problems. These teaching materials cause students not to be able to interpret the material studied in real life, affecting their interest in learning.

The available teaching materials and printed books have not paid attention to students' thinking processes (Choirunnisa, 2016; Hashemi & Branch, 2011). As evidence, the available teaching materials do not begin the description of the material with a study of real problems. These teaching materials tend to emphasize the presence of the equations that apply to thermodynamic material. Teaching materials also have not applied Socratic questions to guide students in finding physics concepts.

Physics learning in schools must emphasize direct experience or inquiry to help students understand their natural surroundings (Kesipudin & Hikmawati, 2009; Masfuah et al., 2011). When students are involved in learning activities, students use their cognitive, affective, and psychomotor abilities so that students can direct their brain abilities to think and learn new concepts that have not been understood (Setyowati et al., 2011). Interest in learning will grow when students do direct experience (Hidayat, 2012; Kurniawan et al., 2018). However, the results of observations and interviews show that the available teaching materials cannot support physics learning in accordance with its nature. Therefore, developing contextual physics teaching materials assisted by Socratic questions on thermodynamic material is necessary.

Contextual physics teaching materials assisted by Socratic questions present problems and phenomena in everyday life into classroom learning, requiring students to be active, collaborate, and inquire. This teaching material pays attention to students' thinking processes because students are always required to think through Socratic questions. Socratic questions in teaching materials can help students identify facts, principles, and physics concepts, elaborate ideas, and evaluate answers to form thinking habits and act critically on students (Brooke, 2006; Redhana et al., 2009; Slezak et al., 2011).

The application of Socratic questions has not been maximized in science learning, especially in physics lessons in Indonesia. Research on using Socratic questions abroad shows satisfactory results for learning physics. (Brooke, 2006) developed A Socratic Questioning Sheet (SQS) as a supplement to applying the Socratic dialogue method. SQS is designed to lead students to the identification of the proper physical principles, the selection of the right approach, the correct equation, and the evaluation of the answers. In Indonesia, research on the development of learning tools and Socratic questions was conducted by (Redhana et al., 2009), which resulted in the use of Socratic questions to improve critical thinking skills. The development research that will be carried out differs from the previous research because the development of teaching materials in this study emphasizes more contextual examples of phenomena and adds aspects of practical activities. Therefore, this research aims to develop contextual physics teaching materials with the aid of Socratic questions to support the improvement of students' critical thinking skills at school, especially in the subject of thermodynamics.

RESEARCH METHODS

This study adopts the Research and Development (R&D) paradigm, which is a development model in which research findings are used to design new products and procedures, which are then systematically tested in the field, evaluated, and refined until they meet the criteria for effectiveness, quality, and are standardized (Gall, 2003). While the development and validation stages use the ADDIE method which consists of the following stages: Analysis-Design-Development-Implementation-Evaluation. The implementation of teaching materials using Socratic questions with Thermodynamics material was carried out for four meetings attended by 64 students in 2 practical classes. The parameters measured in this evaluation stage are the product quality of teaching materials and students' critical thinking skills. There are two main instruments used in the research, namely the Treatment Instrument (contextual physics teaching materials assisted by Socratic questions) and Measurement Instruments (critical thinking ability test) with critical thinking indicators consisting of giving arguments, conducting inductions, evaluating, and making decisions (Ennis, 2009).

RESULTS AND DISCUSSION

Based on the stages in the ADDIE (Analysis-Design-Development-Implementation-Evaluation) method, the process of developing contextual physics teaching materials assisted by Socratic questions on Thermodynamics material has been carried out to train students' critical thinking skills. The description of these stages is explained as follows.

Analysis, preliminary analysis consists of field studies and literature studies. Field studies were conducted using interviews and observations. The results of the field study obtained the following information. (1) The teaching materials used by students in schools have not trained critical thinking skills, tend to emphasize quick formulas and slightly invite students to make discoveries and rarely relate them to real life (contextual). (2) The teacher uses oral questions as a guide to help students solve problems and find equations and physics concepts. The continuous application of oral questions on each material/concept is complex for teachers because of the allocation of time, energy, and many students. (3) Thermodynamics is a material that is considered abstract for students. The material tends to be taught using the lecture method and slightly relates the material to real situations. At the same time, the literature study results are (1) To examine the objectives of learning physics by the applicable curriculum, which can train students' critical thinking skills. (2) Review the research results related to improving students' critical thinking skills with the question method that teachers can apply.

Design, the development plan is carried out by compiling an outline of teaching materials by the applicable curriculum with competencies (1) Describing the properties of a monatomic ideal gas and (2) Analyzing changes in the state of an ideal gas by applying the laws of Thermodynamics. *Development*, developing teaching materials by the outline prepared with the thermodynamics title. The teaching materials consist of two chapters: Chapter I on monatomic ideal gases and Chapter II on thermodynamics. The development process begins with determining the material that becomes a phenomenon in each sub-material and implementation in real life, determining discussion or experiment activities, and making critical thinking questions. The second stage is compiling teaching materials according to the outline, indicators, and selection of phenomena. The development process also includes a feasibility test through expert validation and empirical validation of the content of teaching materials and critical thinking skills test questions for Thermodynamics material.

There are two main sub-chapters in the developed teaching materials: Monoatomic Ideal Gases and Thermodynamics. Each chapter consists of contextual phenomena to support students' critical thinking skills, equipped with help questions using Socratic questions. The main page views in Chapter I and Chapter II are shown in Figure 1.

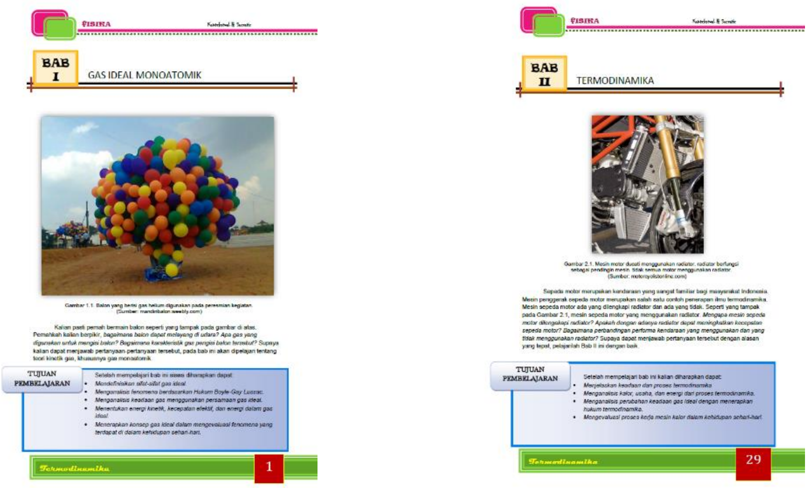


Figure 1. Pages of Chapter I and Chapter II of Teaching Materials

Implementation, the implementation phase is carried out in four classes: two experimental and two control classes. The experimental class learning uses contextual physics teaching materials based on Socratic questions, while the control class uses commonly used teaching materials. The learning in the experimental class using teaching materials looks like in Figure 2. Students are asked to carry out structured experimental activities on the "Experiment" page related to Monoatomic and Thermodynamic Ideal Gas material in groups. At the end of the implementation phase, students are given a test to measure critical thinking skills as well as a response questionnaire to the learning process using teaching materials that have been carried out.

Figure 2. Students doing ‘Experiment’ Part on the Developed Teaching Materials.

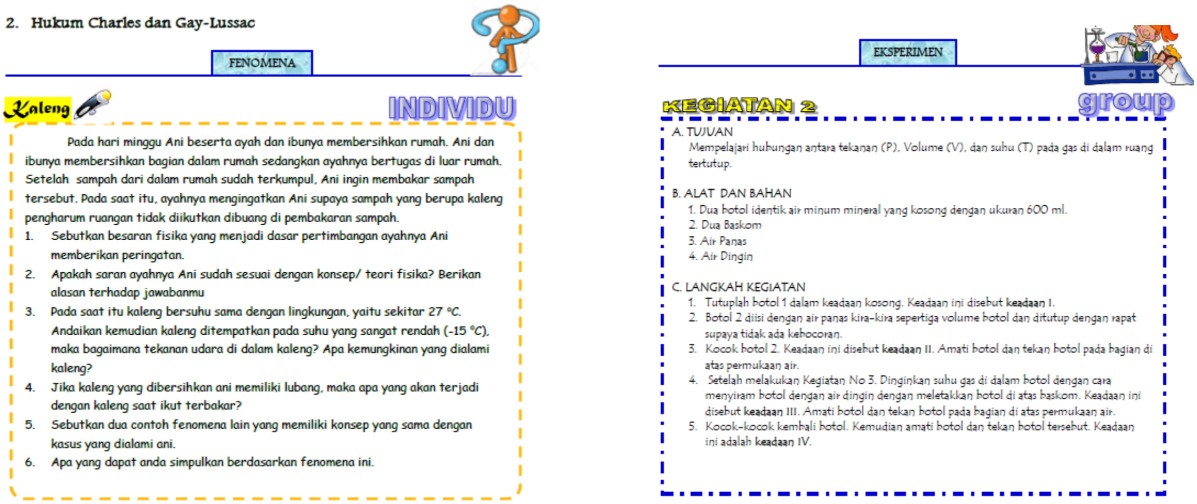
Evaluation, the result of the evaluation phase is to assess the feasibility of teaching materials in terms of "validity, practicality, and effectiveness" (Nieveen, 1999). According to (Arikunto, 2014), if the results of the validity, practicality, and practicality of the media get a percentage of more than 60%, then it can be categorized as a product with good quality value so that it is feasible to use.

The teaching materials were developed to take the primary material of Thermodynamics because teaching on these materials tends to use the lecture method. The lecture method makes it difficult for students to relate the material to problems/facts in the natural environment. Through the product of contextual physics teaching materials based on the Socratic question, students can relate the subject matter or topic to real-life problems to Rusman's (2012) opinion. The linkage between the material and the environment can create meaningful learning for students to understand the natural surroundings more deeply. The content is based on Hidayat's (2012) and Kesipudin & Hikmawati's (2009) opinions.

The characteristics of the teaching materials developed are found in the Phenomenon, Experiments, and Critical Thinking sections. The presentation of material in teaching materials begins with a phenomenon. Phenomena present problems/facts in life. The phenomena section contains questions related to the problems/facts presented. These questions can deepen students' understanding of the relevance of the material being studied to the natural surroundings. In addition, the questions in the phenomena section apply Socratic questions so that they can be instructions for students. This is following the opinion of (Chin, 2007) and (Taylor, 2012) that a series of Socratic questions become student instructions to encourage and guide students thinking, encourage students to generate ideas based on reasoning and prior knowledge, and encourage students to provide information explicitly.

Socratic question-based contextual teaching materials include a tutorial section on experimental sheets that can direct students to be active like scientists to achieve products following the rules of physics learning. This follows the opinion of Kesipudin & Hikmawati (2009), which states that physics is a science born and developed through a scientific process. Experimental/discussion activities are characteristic of inquiry activities (discovery). The experiment/discussion section on teaching materials also follows the steps to achieve contextual learning stated by Rusman (2012).

Figure 3 shows examples of parts advantageous in contextual physics teaching materials assisted by Socratic questions; namely, there are Phenomenon and Experiment components. The "Phenomena" page facilitates support for students' critical thinking skills by providing examples of contextual problems related to the material of Monoatomic Ideal Gases and Thermodynamics by using Socratic questions to direct students to the correct answers. While the "Experiment" page aims to support students' ability to carry out experimental activities that can be carried out in the laboratory or the classroom using specific tools and materials.


2. Hukum Charles dan Gay-Lussac

FENOMENA

Kaleng

INDIVIDU

Pada hari minggu Ani beserta ayah dan ibunya membersihkan rumah. Ani dan ibunya membersihkan bagian dalam rumah sedangkan ayahnya bertugas di luar rumah. Setelah sampah dari dalam rumah sudah terkumpul, Ani ingin membakar sampah tersebut. Pada saat itu, ayahnya mengingatkan Ani supaya sampah yang berupa kaleng pengharum ruangan tidak diikutkan dibuang di pembakaran sampah.

1. Sebutkan besaran fisika yang menjadi dasar pertimbangan ayahnya Ani memberikan peringatan.
2. Apakah saran ayahnya Ani sudah sesuai dengan konsep/ teori fisika? Berikan alasan terhadap jawabanmu
3. Pada saat itu kaleng bersuhu sama dengan lingkungan, yaitu sekitar 27 °C. Andaikan kemudian kaleng ditempatkan pada suhu yang sangat rendah (-15 °C), maka bagaimana tekanan udara di dalam kaleng? Apa kemungkinan yang dialami kaleng?
4. Jika kaleng yang dibersihkan ani memiliki lubang, maka apa yang akan terjadi dengan kaleng saat ikut terbakar?
5. Sebutkan dua contoh fenomena lain yang memiliki konsep yang sama dengan kasus yang dialami ani.
6. Apa yang dapat anda simpulkan berdasarkan fenomena ini.

EKSPERIMEN

KEGIATAN 2

group

A. TUJUAN

Mempelajari hubungan antara tekanan (P), Volume (V), dan suhu (T) pada gas di dalam ruang tertutup.

B. ALAT DAN BAHAN

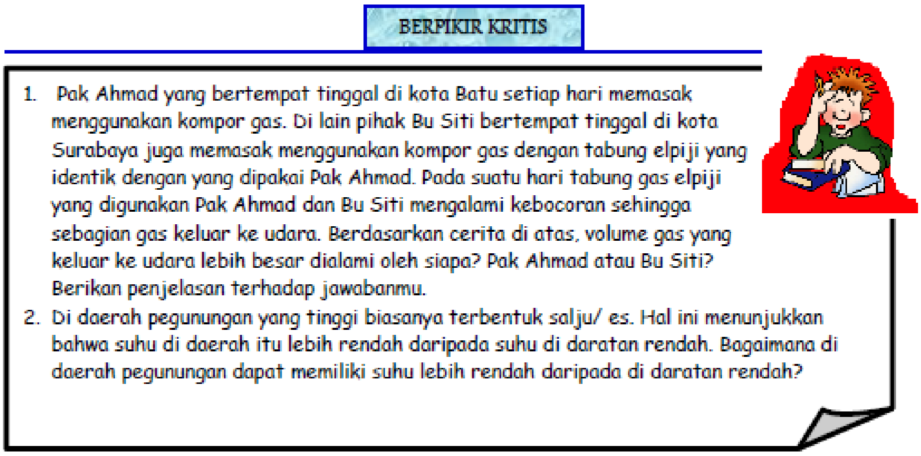
1. Dua botol identik air minum mineral yang kosong dengan ukuran 600 ml.
2. Dua Baskom
3. Air Panas
4. Air Dingin

C. LANGKAH KEGIATAN

1. Tutuplah botol 1 dalam keadaan kosong. Keadaan ini disebut **keadaan** I.
2. Botol 2 diisi dengan air panas kira-kira sepertiga volume botol dan ditutup dengan rapat supaya tidak ada kebocoran.
3. Kocok botol 2. Keadaan ini disebut **keadaan** II. Amati botol dan tekan botol pada bagian di atas permukaan air.
4. Setelah melakukan Kegiatan No 3. Dinginkan suhu gas di dalam botol dengan cara menyiram botol dengan air dingin dengan meletakkan botol di atas baskom. Keadaan ini disebut **keadaan** III. Amati botol dan tekan botol pada bagian di atas permukaan air.
5. Kocok-kocok kembali botol. Kemudian amati botol dan tekan botol tersebut. Keadaan ini adalah **keadaan** IV.

Figure 3. The Phenomenon and Experiment Section as the application of the socratic question

The data collected in this study include (1) critical thinking ability test data for experimental and control classes and (2) student responses to contextual teaching materials assisted by Socratic questions. Critical thinking ability is a complex thinking process that uses basic thinking processes to analyze arguments and generate specific insights. Critical thinking occurs when looking for assumptions, checking assumptions, seeing things from many perspectives, and taking action based on information (Brookfield, 2012). Students' critical thinking ability is measured using critical thinking physics questions in the form of description questions that involve the ability to give arguments, conduct inductions, evaluate, and determine decisions from a physics problem. The questions were empirically validated before being used to measure critical thinking skills in physics. The measurement of students' critical thinking skills in physics was carried out after applying contextual teaching materials assisted by Socratic questions on Thermodynamics material. An example of the critical thinking section in teaching materials is shown in Figure 4 below. In Figure 4, questions involving contextual phenomena are presented to evaluate students' critical thinking skills following the targets for achieving critical thinking indicators, namely giving arguments, conducting inductions, evaluating, and determining experiments.


BERPIKIR KRITIS

1. Pak Ahmad yang bertempat tinggal di kota Batu setiap hari memasak menggunakan kompor gas. Di lain pihak Bu Siti bertempat tinggal di kota Surabaya juga memasak menggunakan kompor gas dengan tabung elpiji yang identik dengan yang dipakai Pak Ahmad. Pada suatu hari tabung gas elpiji yang digunakan Pak Ahmad dan Bu Siti mengalami kebocoran sehingga sebagian gas keluar ke udara. Berdasarkan cerita di atas, volume gas yang keluar ke udara lebih besar dialami oleh siapa? Pak Ahmad atau Bu Siti? Berikan penjelasan terhadap jawabanmu.
2. Di daerah pegunungan yang tinggi biasanya terbentuk salju/ es. Hal ini menunjukkan bahwa suhu di daerah itu lebih rendah daripada suhu di daratan rendah. Bagaimana di daerah pegunungan dapat memiliki suhu lebih rendah daripada di daratan rendah?

Figure 4. Critical Thinking activity column in teaching materials

Based on the indicators of critical thinking skills, the test is carried out with eight questions with a maximum score of 80. Examples of questions and answers for each indicator are as follows.

Giving Arguments.

Question: *Mr. Eko inflates his motorcycle tires using a pump. At that time, Vian (Mr. Eko's son) saw his father pumping. After Mr. Eko finished pumping, Vian tried to use the pump. Vian closed the end of the vent and then pressed the piston. He repeated by leaving the end of the vent open. Why does Vian find it harder to press the piston when the end of the vent is closed than the hole is opened?*

Example of student answers in figure 5:

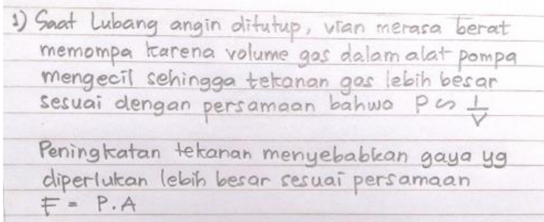


Figure 5. Example of student answers in activity giving arguments

Doing Induction.

Question: *Aruna burns trash with cans with holes in them and burns with other trash. If the ambient air pressure is 1 atm, then make a prediction graph of the relationship between the pressure and the gas temperature in the can.*

Example of student answers in figure 6:

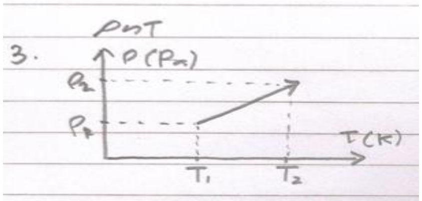


Figure 6. Example of student answers in activity doing induction

Conducting Evaluation.

Question: *Almost every resident in big cities throws organic and inorganic waste into one trash can. This is because residents do not have their land to accommodate waste. Vino is one of the residents of a big city. One day Vino will throw out the trash cans used for methane gas (benzol) containers. Before being disposed of, Vino perforated the can so that it would not be dangerous when in the trash and processed at the Final Disposal Site. Is it true what Vino did? Explain your reasons.*

Example of student answers in figure 7:

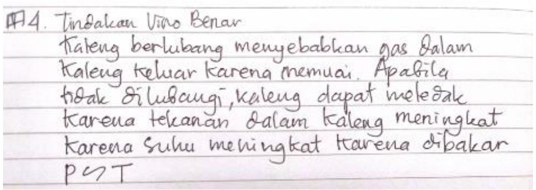


Figure 7. Example of student answers in activity conducting evaluation

Making Decision.

Question: *Suppose you are conducting an experimenting to studying the internal energy of a monatomic gas at a constant volume. What steps can you take to increase the energy in the gas to three times its original value?*

Example of student answers in figure 8:

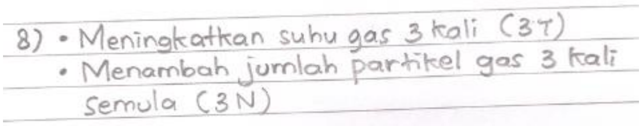


Figure 8. Example of student answers in activity making decision

The value of students' critical thinking skills was analyzed using statistical tests to determine the effectiveness and differences in the results of applying contextual physics teaching materials assisted by Socratic questions on students' critical thinking skills in the experimental and control classes. In summary, the test results are shown in Table 1.

Table 1. Results of Independent t-test of Students' Critical Thinking Ability in Physics

Test Group	Mean	Standard Deviation	t-test	
			t_{count}	t_{table}
Experiment Class	56,03	7,266	2,23	1,96
Control Class	53,05	7,879		

Based on Table 1, if the average score divided by the maximum score is obtained, the physics critical thinking ability of the experimental class students reaches 70% and the control class 66.31%. These results indicate that learning using contextual physics teaching materials based on Socratic questions is 4.31% more effective than learning using teaching materials commonly used in developing critical thinking skills in physics on thermodynamics.

The standard deviation of the experimental class is smaller than the control class, namely 7.266 for the experimental class and 7.879 for the control class. This figure shows that the critical thinking ability of the experimental class students is more evenly distributed, or the critical thinking ability of students with high cognitive is slightly different from that of low cognitive. This shows that learning using contextual physics teaching materials based on Socratic questions can be used effectively to improve the critical thinking skills of all students in physics.

The results of the test using the independent sample t-test showed that the count value of 2.23 was more significant than and t-table of 1.96, so it could be concluded that there was a significant difference between students' critical thinking skills in physics and the application of contextual teaching materials products based on Socratic Questions with no product application. In addition, students critical thinking skills in physics by learning to use contextual physics teaching materials products based on Socratic Questions are higher than those without using contextual physics teaching materials products based on Socratic Questions.

The high ability of students' critical thinking impact of the application of Socratic questions in the form of structured questions in teaching materials, especially in the phenomena section. These questions help students identify facts, and principles/concepts of physics, elaborate ideas, and evaluate answers so that they can form habits of acting and thinking critically in students (Brooke, 2006; Redhana et al., 2009; Slezak et al., 2011). In addition, some questions on teaching materials also require students to think at a higher level, following (Deckert & Wood, 2013)'s opinion that the level and type of questions reflect the level of thinking. The results of the trial (implementation) are also following the opinion which state that through physics education, students can practice thinking critically through the process of problem-solving, concluding, estimating and predicting, generalizing, and thinking creatively (Ergin, 2012; Cahyono, 2016; Pratama & Prastyaningrum, 2016).

Quantitatively, the scores for each critical thinking ability indicator are analyzed as follows. The aim is to find out the highest critical thinking ability possessed by students.

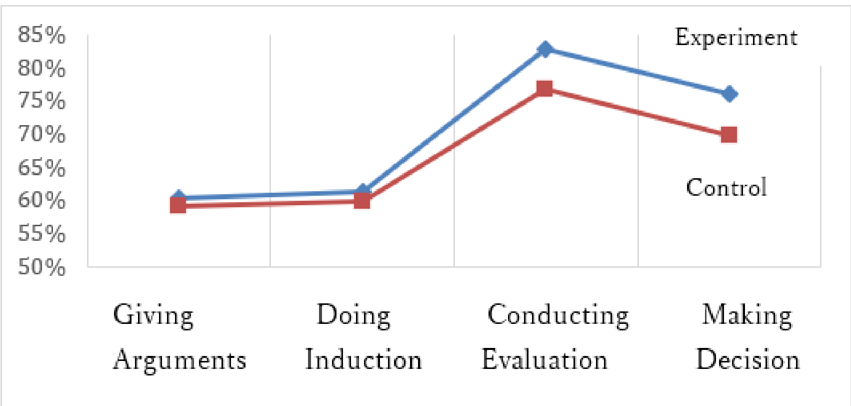


Figure 9. Comparison of Students' Critical Thinking Ability Indicators

Based on the graph in Figure 9, it is known that the student's critical thinking ability is the most dominant in the evaluation ability indicator. Thinking skills emphasize reasoning as the primary cognitive focus (Brookfield, 2012). Through Socratic questions contained in teaching materials, students become accustomed to thinking systematically in analyzing a problem so that it impacts the ability to evaluate.

Positive responses are also a measure of the feasibility of teaching material products that have been applied to students. Based on the results of the response questionnaire, the advantages and disadvantages of teaching materials are obtained, namely: Strengths: (1) there is a phenomenon of studying facts/problems of everyday life before students study the material further; (2) based on Socratic questions that serve as instructions for students to open their initial thoughts about the material to be studied; (3) students can find their concepts so that the accepted concepts are more embedded in their minds; and (4) empirically tested in developing physics critical thinking skills. Weaknesses: limited questions that describe applications or problems in everyday life and the number of Socratic questions that are not evenly distributed in each material. In addition, the teaching materials' weakness is only limited to thermodynamic material. Learning physics through natural phenomena that occur in nature around students gives more meaning and helps students learn to master the subject matter more quickly. According to Satriawan (2016), the contextual approach is meaningful learning and considers the learning objectives to be situations that exist in that context, the context helps students learn meaningfully and also expresses abstract things. Ibrahim (2014) explained that integrating local wisdom in educational and learning activities has the potential to bring up an innovation with novelty and local wisdom as an inspiration, which brings up new ideas in learning.

CONCLUSION

Socratic question-based contextual physics teaching materials have been empirically tested and can be used to develop physics students' critical thinking skills. The results showed that (1) the process of developing contextual physics teaching materials assisted by Socratic Questions had met the product quality criteria, which included validity, practicality, and effectiveness (2) there was a significant difference between students' critical thinking skills in physics using Socratic-assisted contextual teaching materials—question without product application. In addition, it was found that the profile of students' critical thinking skills in physics learning using contextual physics teaching materials products Socratic questions was higher than in learning that did not use contextual physics teaching materials assisted by Socratic questions (with critical thinking indicators consisting of giving arguments, induction, evaluating, and make decisions).

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