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Development of Statistical Physics Teaching Materials Based on Three Levels of Representation to Improve Mental Models

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Abstract: This research aims to produce Statistical Physics teaching materials based on three levels of representation to improve mental models. To achieve this goal, the research design used is Design and Development Research (DDR) which consists of three stages, namely development, validation, and implementation. At the stage of developing teaching materials, the 4STMD method is used which consists of the stages of selection, structuring, characterization, and didactic reduction. This research is limited to the selection and structuring stages. The instruments used are a review sheet of suitability of each aspect, a validation sheet, and a practicality questionnaire. The data obtained were analyzed using CVR and PCM. Based on the results of data analysis, it was obtained that the teaching materials was in accordance with the indicators, concept labels, substance context, and pedagogical context. The teaching materials developed are valid and practical to use. Teaching materials can also improve students' mental models. Researchers recommend using this teaching material in Statistical Physics lectures to improve students' mental models.

Keywords: Teaching material, Statistical physics, Three Levels of Representation, Mental model, 4STMD

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1. Introduction

Statistical Physics is a branch of Physics that utilizes statistical methods in explaining Physics phenomena. Statistical Physics tries to bridge how microscopic perspectives are able to explain macroscopic phenomena through statistical analysis. Students need a high level of understanding in studying the concepts of Statistical Physics. However, students still have difficulty understanding the material and misconceptions during lectures (Afrizon et al., 2019; Crossette et al., 2021; Riandry et al., 2017). This can be caused by complicated and less interesting material for students. Based on this, it can be concluded that it is important for lecturers to improve student understanding in Statistical Physics.

Students' understanding is influenced by their knowledge structure or mental model that they have (Batlolona & Souisa, 2020). Mental model is a person's internal representation in accessing their knowledge structure so that it can be used to solve problems, understand phenomena, see actual phenomena, and as a good predictor of the final state of phenomenon (Batlolona & Diantoro, 2023; Fratiwi et al., 2020; Sağlam-Arslan et al., 2020). Mental model is related to the way students organize knowledge and explicitly explain conjectures about a phenomenon. Mental models are important to improve through the learning process because they relate to the way students construct knowledge and use it to solve problems. Students need to continue to improve, modify, and reorganize mental model they have in each experience through the learning process. Mental models depend on previous experiences and new skills learned about the world gained through experience. Mental models help learners to limit the flow of information and select the most important information in each situation so that it can guide someone in making predictions and decisions (Suomala & Kauttonen, 2022). However, only a small percentage of students have good mental model characteristics (Ashel et al., 2024b). In addition, there is still little research on mental models in Statistical Physics lectures (Ashel et al., 2024a).

One way that can be done to improve mental models is through the use of Statistical Physics teaching materials based on three levels of representation. Teaching materials are all forms materials that are arranged in a structured and systematic manner that are designed in accordance with the demands of the curriculum, become a learning resource for students, and become materials or materials for educators in carrying out teaching and learning activities (Anwar, 2023; Dalifa et al., 2024). Teaching materials that are interesting and easy to understand can increase students' motivation in learning a material (Dalifa et al., 2024). However, students and lecturers still have difficulty in finding interesting and easy-to-understand learning resources. The learning resource used in Statistical Physics lectures is textbooks so that learning feels more monotonous and boring (Ashel et al., 2024b).

There are many types of teaching materials that can be found, one of which is modules. Modules differ from other teaching materials because they can facilitate students to learn independently either with or without teacher guidance (Depdiknas, 2008). Modules will be useful when they can be used easily. Modules must be able to

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describe the competencies to be achieved to facilitate the diversity of students. Modules must be presented using good, engaging language, and complemented by illustrations. In this study, the teaching materials developed are modules.

The three levels of representation consist of macroscopic, microscopic, and symbolic levels (Pande & Chandrasekharan, 2017). There are often used in Chemistry learning, but they are also important to use in Physics learning. In Physics learning, deeper understanding occurs in the progression from qualitative content (referring to the sub-micro level) to quantitative (referring to the symbolic level). For example, force is not a substance but an interaction between substances and is a core concept for understanding the mechanism of a phenomenon. Force can be represented at the sub-micro level which is categorized as something that is not a substance that cannot be observed directly (Park et al., 2020). The symbolic level plays a role when analyzing forces using mathematical equations, which will help to achieve a deeper understanding.

The use of representation can help students to improve their understanding so that it can reduce cognitive load (Hochberg et al., 2020; Wu & Liu, 2021). The implementation of the three levels of representation can overcome students' difficulties in understanding the material and contribute to the formation of meaning to concepts (Anwar, 2023). One of the advantages of the developed teaching materials is that the supporting materials consist of three levels of representation. The macroscopic level is provided through phenomena that can be observed by students or technology that applies the concept of Statistical Physics. Explanations at the microscopic level are provided through simulations and videos that can be accessed through barcodes or links that are available in each material. Simulation and video are one of the efforts to display visualization of phenomena that cannot be observed directly. Learning activities by integrating visualization can increase active participation and understanding of students. Visualization can help in the formation of stored mental models. The use of submicro images in learning can help students build appropriate mental models for the phenomena being studied (Locatelli & Davidowitz, 2021). In addition, explanations are also provided at the symbolic level through equations that are derived in detail so that students can study Statistical Physics materials independently.

In addition, the three levels of representation have a relationship with the mental model. The students' ability to change conceptual knowledge or knowledge structures depends on the flexibility of their internal representations, where this flexibility depends on the level of representation (Mansyur et al., 2022). A person's mental model can be identified by the way they represent a phenomenon into three levels of representation. Three levels of representation are one way to categorize mental models (Jansoon et al., 2009). The use of macroscopic and microscopic levels in energy transfer material can facilitate students' understanding and develop scientific mental models (Kurnaz & Eksi, 2015). Mental models consist of simple representations that can motivate the construction of mental models to occur from the beginning (Franco & Colinvaux, 2000). However, there has not been much research on the three levels of representation in Physics learning, especially in Statistical Physics lectures.

Based on the background and problems, this research aims to produce Statistical Physics teaching materials based on three levels of representation to improve mental models. The research questions that will be answered through this study are: 1) how to analyze the material developed in the Statistical Physics teaching materials?; 2) how is the validity of Statistical Physics teaching materials based on three levels of representation?; and 3) how practical are the teaching materials in improving mental models?.

2. Method

This research aims to produce Statistical Physics teaching materials based on three levels of representation to improve mental models. To achieve this goal, Design and Development Research (DDR) research design is used. The design of this study focuses on the development process, which starts from the design to the evaluation process, to build a device based on a needs analysis (Lah et al., 2024; Richey & Klein, 2007). The design of this research consists of three stages, namely development, validation, and implementation as shown in Figure 1.

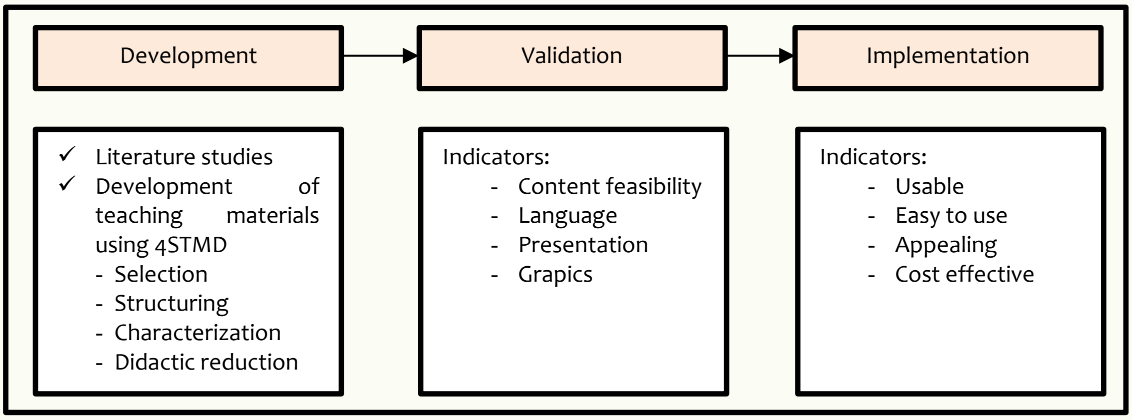

Figure 1. Research design

The first stage is the development of teaching materials. At this stage, literature studies and teaching materials development are carried out. The teaching material development method used is the Four Steps Teaching Material Development (4STMD) method (Anwar, 2023; Anwar et al., 2023; Khoirunnisa et al., 2023; Zaldy et al., 2022). 4 STMD is a method of developing teaching materials that consists of detailed stages and has certain criteria that are in accordance with the curriculum. The 4STMD stage consists of selection, structuring, characterization, and didactic reduction. This research is limited to the selection and structuring stage because the subject of this research is university students. At the selection stage, material analysis is carried out based on the applicable curriculum, material development, and selection of contexts related to the material. Furthermore, at the structuring stage, the structure of teaching materials is developed in the form of a concept map, macro

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structure, and three levels of representation. The final product of this structuring stage is the development of a draft teaching material that is in accordance with the results of the analysis of the material and structure that has been prepared. Each stage is reviewed by three experts, namely lecturers who teach the Statistical Physics course. The instrument used was a review sheet with two answer criteria namely "Yes" and "No".

The second stage is the validation of teaching materials. This teaching material is validated by five validators who are experts in the field of education and Statistical Physics content. In this study, content validation is carried out because rational analysis from experts in related fields is needed to produce valid products. The instrument used is a validation sheet consisting of two assessment criteria, namely "Yes" and "No". Assessment indicators consist of aspects of content feasibility, language, presentation, and graphics (Depdiknas, 2008). Yes answers are given a grade of 1 and No answers are given a grade of 0. The data obtained was analyzed quantitatively using Content Validity Ration (CVR) and Percentage Calculation Method (PCM). CVR developed by Lawshe (1975) is an approach used to determine the suitability of items measured based on expert assessments. CVR is calculated using the formula:

$$CVR = \frac{n_e - \left(\frac{N}{2}\right)}{\frac{N}{2}} \quad (1)$$

$$CVI = \frac{\sum CVR}{Number\ of\ asessment\ indicators} \quad (2)$$

n_e is the number of responses stating Yes and N is the number of experts. The average CVR of each indicator is called the Content Validity Index (CVI). The critical value of CVR for five experts with a level of significance of 0.1 is 0.736 (Wilson et al., 2012). Teaching materials are said to be valid if the CVI score is higher than the critical value. In addition, in this study, analysis was also carried out using the PCM method with the following formula (Ping, 2020).

$$PCM = \frac{Total\ experts'score}{Total\ maximum\ score} \times 100\% \quad (3)$$

Qualitative analysis is carried out by summarizing and coding suggestions and inputs from experts.

The third stage is the implementation of teaching materials. Teaching materials that have been valid are tested in Statistical Physics lectures at one of the universities in Padang City. The subjects of this study are 19 students who take the Statistical Physics course. This teaching material is tested on the material on the distribution function of velocity, rate, and molecular energy. Data was collected through a practicality questionnaire to determine the practicality of teaching materials developed based on student perceptions. This questionnaire uses a Likert scale consisting of four assessment criteria, namely Strongly Agree (score 4), Agree (score 3), Disagree (score 2), and Very Disagree (score 1). The assessment indicators used include usable, easy to use, appealing, and cost effective aspects. The data obtained were analyzed quantitatively using the PCM method with the criteria of very weak (0-20), weak (21-40), moderate (41-60), strong (61-80), and very strong (81-100) (Mufit et al., 2022). Meanwhile, qualitative analysis was carried out by summarizing the responses given by students.

3. Result and Discussion

Development of Teaching Materials

The development of Statistical Physics teaching materials based on three levels of representation is carried out using the 4STMD method. In this study, the stage of the 4STMD method is limited to the selection and structuring stage. The selection stage consists of three steps, namely the development of indicators and concept labels, the development of material from concept labels, and the development of context (Anwar, 2023). The development of indicators and concept labels is carried out by analyzing the Statistical Physics Semester Learning Plan. Indicators are developed from the Sub-Course Learning Outcomes (Sub-CLO). In this study, three Sub-CLO were selected, namely gas kinetic theory, distribution function, and transport phenomena. Based on the results of the analysis of Sub-CLO, 19 indicators were obtained. These indicators are simplified into concept labels. The relationship between indicators and concept labels in one of the Sub-CLO is shown in Table 1.

Table 1. Development of indicators and concept labels based on Sub-CLO

Sub-CLO	Indicator	Concept labels
1. Able to cooperate and show a good social attitude in discussing phenomena or problems of the distribution function 2. Able to communicate arguments when given questions related to the material 3. Able to determine the speed distribution function, rate distribution function, and energy distribution function of the molecule and its application 4. Able to implement distribution functions to identify, analyze, and solve problems comprehensively	1. Explain the basic assumptions used to formulate the velocity distribution function and the molecular rate distribution function 2. Determine the velocity distribution function and the molecular rate distribution function in general form 3. Illustrate the graph of the velocity distribution function and the molecular rate distribution function 4. Determine the value of the average rate, the average square rate, the rms rate, the rate that produces the maximum value distribution function 5. Determine the function of energy distribution 6. Illustrate the graph of the energy distribution function 7. Solve the application-related problems of the velocity, rate, and energy distribution function of the molecule	Molecular Speed and Rate Distribution Function - Maxwell-Boltzmann Speed Distribution Function - Maxwell-Boltzmann Rate Distribution Function - Maxwell-Boltzmann Energy Distribution Function

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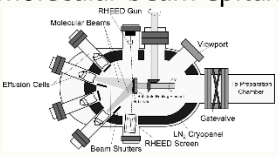
The second step is to develop the material based on the concept label. Based on the concept label, it was identified that there are three main materials, namely gas kinetic theory, molecular distribution function, and transport phenomena. Any concept label developed into material must be based on relevant and reliable sources. These sources can be books that have been used by many scientists, reliable articles, research results, and other relevant sources (Khoirunnisa et al., 2023). The purpose of this stage is so that the teaching materials developed can be accounted for the truth.

The third step is context development. In the 4STMD method, there are two types of contexts, namely the substance context and the pedagogical context (Anwar, 2023). The substance context is the context of teaching materials that are related to phenomena, symptoms, facts, data, and benefits in various areas of life. Through this context, students are expected to be able to connect the knowledge they have with the material they are learning. They can explain the phenomena given using the information they have obtained through the lecture process. This process is called assimilation and accommodation. This process is concerned with the formation of knowledge structures or mental models. Furthermore, the pedagogic context is the context in which teaching materials are used as a means or medium to develop values, attitudes, and skills. This teaching material was developed to improve the mental model so that a pedagogic context was developed that referred to the characteristics of the mental model. Table 2 shows the substance and pedagogic context of one of the materials.

Table 2. Substance and pedagogy context related to the material

Description of the material	**Substance context**	**Pedagogic context**
In the concept of gas kinetic theory, it has been assumed that gas molecules have different velocities. However, this theory has not been able to answer the question of how many molecules have velocity in a given direction and magnitude. The solution to this problem is to determine the	The concept of the velocity distribution function can be applied in the field of atomic physics, namely in calculating the number of molecules at a certain speed resulting from a beam of neutral particles. This experiment was also directly used to test Maxwell's law of distribution. This experiment is also applied in the manufacture of several technologies such as Molecular Beam Epitaxy (MBE). 	One of the important techniques in atomic physics is to produce collimated beams of neutral particles. This m mass molecule is placed in a container where there is a small gap in the wall of the container. Molecular beams can be generated by making gas molecules exit these small gaps towards areas that have pressures kept low. In order for the resulting molecule to have a gaseous form, the container is heated to a temperature of T so that the molecule moves at the rate of v. If the gap is small enough that it does not affect the equilibrium of the gas in the container, what is the effective speed (vrms) of the molecules in the container and the effective speed of the molecules

Description of the material	Substance context	Pedagogic context
speed distribution function.	(Source: https://www.eetimes.eu/unlocking-the-potential-of-molecular-beam-epitaxy/)  (Source: https://en.m.wikipedia.org/wiki/File%3AMolecular_Beam_Epitaxy.png)	exiting the gap? Also determine the pressure that the molecule exerts against the container wall. State the answer in k, T, m, and n. Stages carried out to solve the problem: identifying the problem, collecting data or information, assimilation and accommodation, presenting tentative arguments, implementing solutions, analyzing and synthesizing the results of the discussion, and evaluation

The suitability analysis of the three steps is carried out using equation 1. The review process was carried out to see the suitability of indicators with concept labels, the suitability of the material with concept labels, the suitability of the substance context with the material, and the suitability of the pedagogical context with the material. Table 3 shows the CVI value in the review results.

Table 3. The results of the review by experts at the selection stage

Assessed aspects	CVI	Category
Indicator conformity with concept labels	1	Appropriate
Material conformity with concept labels	1	Appropriate
Suitability of substance context to the material	1	Appropriate
Relevance of pedagogical context to the material	1	Appropriate

In Table 3, it can be seen that the CVI value for all aspects is 1. This value is higher than the critical value of 0.736. Therefore, it can be concluded that all aspects are in accordance and interconnected with each other.

The next stage in the 4STMD method is structuring. Structuring is arranging the structure and systematics of teaching materials through three forms, namely concept maps, macro structures, and three levels of representation. Concept maps aim to determine the relationship between one concept and another. These concept maps are displayed in the teaching materials so that students can relate the material they are learning in their knowledge and help them develop their knowledge (Zaldy et al., 2022). Concept maps can improve students' ability to formulate concepts, connect ideas, and understand the relationships between concepts. This helps students build mental models because it involves visual reconstruction of knowledge. The use of concept maps can improve student achievement and reduce the mental effort required in learning Physics (Alsuraihi, 2022). The structure of knowledge they

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possess becomes whole and not separate. This affects the mental model they have. The developed concept map is shown in Figure 2.

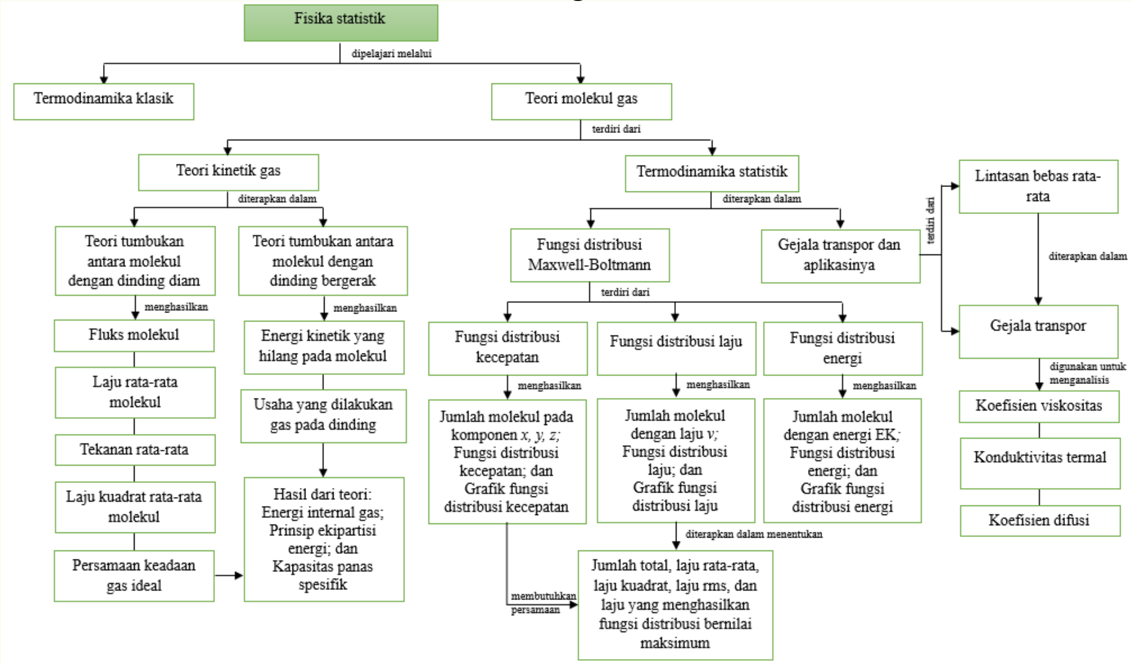

Figure 2. Concept maps in Statistical Physics teaching materials

The macro structure is arranged as a guide or outline for the development of Statistical Physics teaching materials. The macrostructure shows the depth and breadth of the material. The related concepts are mapped in two forms, namely downward (progression dimension) and sideways (elaboration dimension). An example of the macro structure developed is shown in Figure 3.

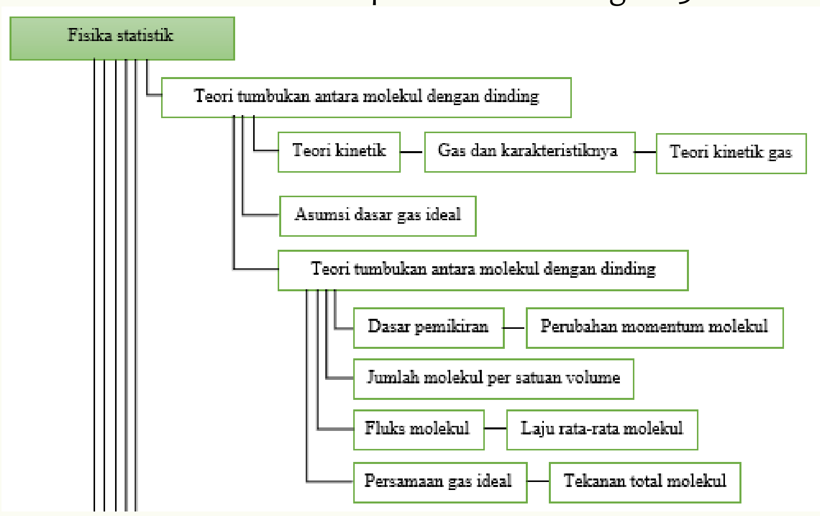

Figure 3. Macro structure of Statistical Physics teaching material

The last form is the three levels of representation. The three levels of representation consist of macroscopic, microscopic, and symbolic levels (Pande & Chandrasekharan, 2017). The three levels of representation in the teaching materials will help students to create the mental model they should have correctly (Anwar, 2023). Mental models will be well formed when students are able to connect the three levels of representation. Table 4 shows an example of three levels of representation in one of the materials in the Statistical Physics teaching material.

Table 4. Three levels of representation on the matter of the distribution function of the velocity and rate of the molecules

Material	Macroscopic	Microscopic	Symbolic
In the concept of gas kinetic theory, it has been assumed that gas molecules have different velocities. However, this theory has not been able to answer the question of how many molecules have velocity in a given direction and magnitude. The solution to this problem is to determine the speed distribution function	The concept of the velocity distribution function can be applied in the field of atomic physics, namely in producing molecular beams in MBE technology 	The velocity distribution function is used in molecular beam techniques to calculate the number of atoms at a given speed in the molecular beam. This beam is generated when gas molecules exit from a small gap in the container wall. The higher the temperature, the greater the speed and the more molecular beams produced.	Maxwell-Boltzmann rate distribution function: $f(v) = \frac{dN_v}{dv} = \frac{4N}{\sqrt{\pi}}\left[\frac{m}{2kT}\right]^{\frac{3}{2}} v^2 e^{-\frac{mv^2}{2kT}}$ The higher the temperature, the lower the peak of the curve and shifts towards a greater rate, the wider the curve, and the greater the maximum speed achieved.

In this teaching material, microscopic explanations are also equipped with simulations and videos. Microscopic events cannot be observed directly so tools are needed to explain them. Videos as a learning medium can provide direct examples of material that is difficult to practice for educators and students (Fitriansyah, 2023). This visual representation helps students to connect experiences with certain concepts and helps students understand abstract concepts. Explanations given through pictures and words can improve cognitive and construct mental models so that teaching materials based on three levels of representation are needed (Canlas, 2021; Mansyur et al., 2022). The structuring stage is the basis for developing draft teaching materials.

The teaching materials used in learning must have a unique and attractive form so that they can encourage students' interest in participating in the learning process (Dalifa et al., 2024). In this study, the type of teaching materials developed is modules. A module is a book written with the aim that students can learn independently without or with the guidance of educators. At least the module consists of learning instructions, competencies to be achieved, content of the material, supporting information, exercises, work instructions, evaluation or feedback on the results of the evaluation (Depdiknas, 2008). In this study, the teaching materials consist of

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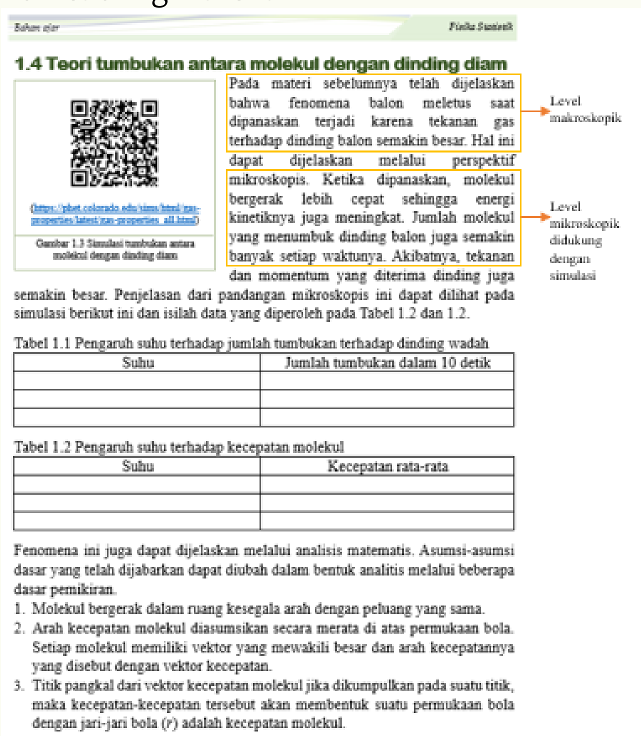
several components, namely covers, table of contents, learning instructions, competencies to be achieved, concept maps, supporting materials, exercises, evaluations, glossaries, indexes, and references.

The material in the Statistical Physics teaching materials based on three levels of representation is developed into six modules, namely the collision theory between molecules and static walls, the collision theory between molecules and moving walls, the distribution function of molecular velocity and rate, the distribution function of molecular energy, the average free trajectory, and transport phenomena. The supporting material for each module is developed based on three levels of representation. At the macroscopic level, phenomena that can be directly observed by students or the application of the material in life are given. At the microscopic level, explanations are given from a microscopic perspective through simulations or videos. The simulation or video can be accessed through the barcode or link provided. Computer simulation or working in groups is one way to build models (Cascarosa et al., 2021). Furthermore, the symbolic level is in the form of symbols, algebraic formulas, and equations. These three levels of representation provide a complete understanding for students because they provide an explanation of a phenomenon or problem from three different perspectives (Praisri & Faikhamta, 2020). Better understanding will emerge when students can understand and represent ideas about the same object at all three levels of representation (Park et al., 2020). Students can build their knowledge through three levels of representation so that their mental model can be built properly. Figure 4 shows a snippet of the supporting materials in the Statistical Physics teaching material.


Bahan ajar — Fisika Statistik

1.4 Teori tumbukan antara molekul dengan dinding diam

(https://phet.colorado.edu/sims/html/gas-properties/latest/gas-properties_all.html)

Gambar 1.3 Simulasi tumbukan antara molekul dengan dinding diam

Pada materi sebelumnya telah dijelaskan bahwa fenomena balon meletus saat dipanaskan terjadi karena tekanan gas terhadap dinding balon semakin besar. Hal ini dapat dijelaskan melalui perspektif mikroskopis. Ketika dipanaskan, molekul bergerak lebih cepat sehingga energi kinetiknya juga meningkat. Jumlah molekul yang menumbuk dinding balon juga semakin banyak setiap waktunya. Akibatnya, tekanan dan momentum yang diterima dinding juga semakin besar. Penjelasan dari pandangan mikroskopis ini dapat dilihat pada simulasi berikut ini dan isilah data yang diperoleh pada Tabel 1.2 dan 1.2.

Level makroskopik

Level mikroskopik didukung dengan simulasi

Tabel 1.1 Pengaruh suhu terhadap jumlah tumbukan terhadap dinding wadah

Suhu	Jumlah tumbukan dalam 10 detik

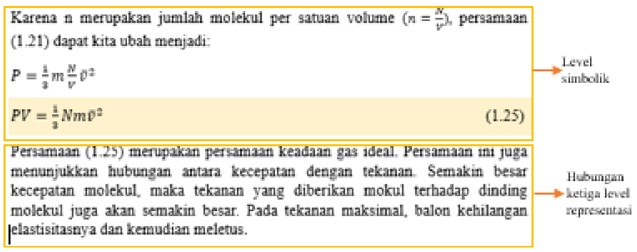
Tabel 1.2 Pengaruh suhu terhadap kecepatan molekul

Suhu	Kecepatan rata-rata

Fenomena ini juga dapat dijelaskan melalui analisis matematis. Asumsi-asumsi dasar yang telah dijabarkan dapat diubah dalam bentuk analitis melalui beberapa dasar pemikiran.

1. Molekul bergerak dalam ruang kesegala arah dengan peluang yang sama.
2. Arah kecepatan molekul diasumsikan secara merata di atas permukaan bola. Setiap molekul memiliki vektor yang mewakili besar dan arah kecepatannya yang disebut dengan vektor kecepatan.
3. Titik pangkal dari vektor kecepatan molekul jika dikumpulkan pada suatu titik, maka kecepatan-kecepatan tersebut akan membentuk suatu permukaan bola dengan jari-jari bola (r) adalah kecepatan molekul.

⋮


Karena n merupakan jumlah molekul per satuan volume ($n = \frac{N}{V}$), persamaan (1.21) dapat kita ubah menjadi:

$$P = \frac{1}{3} m \frac{N}{V} \bar{v}^2$$

$$PV = \frac{1}{3} N m \bar{v}^2 \quad (1.25)$$

Persamaan (1.25) merupakan persamaan keadaan gas ideal. Persamaan ini juga menunjukkan hubungan antara kecepatan dengan tekanan. Semakin besar kecepatan molekul, maka tekanan yang diberikan mokul terhadap dinding molekul juga akan semakin besar. Pada tekanan maksimal, balon kehilangan elastisitasnya dan kemudian meletus.

Figure 4. Snippets of three levels of representation in the Statistical Physics teaching material

Student activities in teaching materials use the Argumentation Based On Three Levels of Representation (AB3LR) model. This model consists of seven stages, namely identifying problems or phenomena, collecting data or information, assimilation and accommodation, presenting tentative arguments, implementing solutions, analyzing and synthesizing the results of discussions, and evaluation. At the stage of identifying problems, students are given the opportunity to analyze problems from three perspectives. This process will make it easier for students to understand the problems given based on the structure of their knowledge.

Teaching Materials Validation Results

The teaching materials that have been developed are then validated by five experts. The feasibility of teaching materials is assessed based on four assessment indicators, namely the feasibility of content, language, presentation, and graphics. The results of the validation of the Statistical Physics teaching materials based on three levels of representation are shown in Table 5.

Table 5. The results of the validation of Statistical Physics teaching materials are based on three levels of representation

Assessment indicator	CVI	PCM (%)
Feasibility of content	1	100
Language	1	100
Presentation	1	100
Graphic	0,76	88

Table 5 shows that the CVI value for each aspect is above the critical value and the PCM value is above 80%. This value shows that the teaching materials for Statistical Physics based on three levels of representation are valid and can be used in research and learning. In the graphics component, the CVI value is less than 1. This aspect is not optimal because one of the experts stated that the size of the writing on the teaching materials is too small and the size of the teaching materials is also small. The layout and writing need to be enlarged and clarified. The cover design can be made more attractive.

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Results of Teaching Materials Trials

The validation results show that the teaching materials are valid and can be used in the trial. The trial aims to determine the practicality of using teaching materials in the field. This teaching material is applied to a Statistical Physics lecture at one of the universities in Padang City. The practical aspect of teaching materials consists of several components as shown in Table 6.

Table 6. Results of the practicality of the application of teaching materials

Assessment indicator	Average (%)	Description
Usable	88,16	Very strong
Easy to use	89,47	Very strong
Appealing	83,42	Very strong
Cost effective	83,42	Very strong

Table 6 shows that the average of each indicator is in the range of 81-100%. This means that Statistical Physics teaching materials based on three levels of representation practical for use in lectures. Students stated that the teaching materials used were interesting and easy to understand. Teaching materials can add insight and knowledge. The material is detailed and structured so that it is easy to understand. 84.21% of students agree that teaching materials are useful for building knowledge structures or mental models. Three levels of representation can increase understanding and improve mental models (Hochberg et al., 2020; Kurnaz & Eksi, 2015). Explanations through three levels of representation (pictures and words) help students connect the concepts being studied and reduce the level of abstraction of the material (Canlas, 2021; Mansyur et al., 2022). Students will have a complete understanding when given an explanation from three perspectives (Praisri & Faikhamta, 2020). Three levels of representation make teaching materials more interesting and easier to understand so that they can increase students' motivation in studying Statistical Physics.

This research has limitations in its development process. The teaching materials developed are only for three sub-CLO. The implementation of the trial was carried out on a small scale with a limited number of students. In the next research, it is hoped that it can complete the material for all sub-CLO so that the teaching materials are used for one semester. The number of meetings and students can also be increased so that it is more visible how the influence of teaching materials on the improvement of students' mental models. The researcher recommends the use of teaching materials based on three levels of representation in Statistical Physics lectures to improve mental models. This teaching material can be a reference source that is easy for students to understand.

4. Conclusion

Statistical Physics teaching materials based on three levels of representation developed using the 4STMD method are in accordance with indicators, concept labels, substance contexts, and pedagogical contexts. Teaching materials consist of several components, namely covers, table of contents, learning instructions, competencies to be achieved, concept maps, supporting materials, exercises, evaluations, glossaries, indexes, and references. The teaching materials produced are valid and suitable for use based on the assessment of experts. In addition, Statistical Physics teaching materials based on three levels of representation practical for use in lectures and can improve the knowledge structure or mental model of students.

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