Exploring the Effects of E-Multimedia Animation (E-MMA) on Materials Microstructural of Atomic Slip Plane on Materials Mechanical Properties: Conceptual Mastery and Problem-Solving Skills

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ARTICLE INFO	ABSTRACT
	This study aims to explore the effects of e- Multimedia Animation (E-MMA) on microstructure shift materials on atomic properties of engineering materials with a focus on conceptual mastery and Problem-solving skills. The research sample consisted of 32 JPTM FPTK UPI students who were prospective vocational teachers. The level of difficulty of the engineering materials course varies in each subject, with the majority of students experiencing difficulties in the subject of phase diagrams (68.8%), shifts or movements of atoms and crystal structures (25.0%), and other subjects (6.3%). This research uses research and development methods with qualitative and quantitative approaches. The research instruments used are tests, rubrics, and questionnaires that have been validated by experts. The data processing process is carried out through qualitative and quantitative descriptive analysis, including the percentage of N-gain to measure the improvement of learning outcomes. The results showed that the application of E-MMA to atomic shear plane material resulted in increased mastery of concepts and problem-solving skills. The experimental class using E-MMA achieved an increase in mastery of concepts with an average of 62.82%, while the control class using image media only achieved an increase of 15.52%. This shows that E-MMA is effective in increasing mastery of concepts. In addition, the use of E-MMA also improves problem-solving skills. The experimental class achieved an increase in problem-solving skills by an average of 79.72%, while the control class only achieved an improvement of 15.98%. These results show that E-MMA makes a significant contribution to improving problem-solving skills. Based on these findings, it can be concluded that E-MMA is an effective method for improving mastery of concepts and problem-solving skills in microstructural shift materials in atomic properties of engineering materials. The implementation of E-MMA can help students understand and overcome the difficulties associated with atomic shear planes.

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1. Introduction

The background of this research highlights the scientific aspects of understanding the difficulties faced by some Engineering students in the Material Engineering course [1,2]. A previous study by Komaro [3] showed that around 25% of students have difficulty in learning and understanding concepts in Engineering Materials. Materials Engineering courses are often considered abstract, complex, and dynamic. The abstract nature includes theoretical concepts that cannot be observed or felt directly by students. For example, crystal structure, material strength, thermal, and mechanical are often difficult to understand and relate to the real world [4,5]. In this context, this study aims to present a better scientific approach to overcoming these difficulties and improve students' mastery of concepts and problem-solving skills on the material of the sliding field of Engineering Materials.

In addition, the importance of a scientific approach in studying the Material Engineering course is also reflected in the complexity of the material. Students are required to understand the complex relationships between various material parameters, such as chemical composition, crystal structure, mechanical properties, and heat treatment. Understanding the complex interactions between these factors and their impact on material properties is a significant challenge for some students [4].

Finally, the dynamic nature of the field of Material Engineering adds to the level of difficulty in studying it. The field is constantly undergoing development and innovation, with the emergence of new materials, new production technologies, and different material applications. Students need to keep up with the latest developments in this field to stay relevant in mechanical engineering practice [4].

Limited access to reference books is also the main reason (Table 1). Students are faced with financial obstacles due to the relatively expensive price of reference books, especially original textbooks which cost around IDR 585,000. This results in not all students having access to the necessary reference books. In addition, there is a language barrier, where most students do not master English which is the original language in these original texts [6,7]. As a result, students have difficulty accessing the materials needed to learn concepts in engineering materials.

Table 1
Students who have a main reference book in the engineering materials course

No	Reference Books	Language	Percentage of students who own books				
			2008	2009	2010	2011	2012
1	*Material Science and Engineering, an Introduction*	English	0	0	0	0	0
2	*Principles of Material Science Engineering*	English	0	0	0	0	0
3	*Mechanical Metallurgy*	English	0	0	0	0	0
4	*Materials Science and Technology*	Indonesian	48	55	59	58	76

The second problem is the difficulty in understanding concepts that are abstract, complex, and dynamic (Table 2). The Materials Engineering course presents concepts that require deep mastery of atomic structure, changes in atomic structure, and atomic interactions that affect metal properties. The latest data shows that only around 41.6% of students are able to solve problems related to these concepts [2]. This indicates that some students face difficulties in understanding abstract, complex, and dynamic concepts, which become obstacles in learning technical materials.

The difficulties faced by some students in understanding the Engineering Materials course have a negative impact on learning and mastering the concepts needed in the field of mechanical engineering. Therefore, this study aims to explore educational strategies or innovations that are effective in improving students' mastery and skills in learning and understanding abstract, complex, and dynamic material. One of the excellent methods is using multimedia [8-13].

Table 2
JPTM students who master atomic crystal structure materials and their characteristics in the Atomic Materials course

No	Types of Exams	Percentage of students who master the material				
		The crystal structure of atoms and their characteristics				
		2008	2009	2010	2011	2012
1	UTS	52	57	63	44	50
2	UAS	24	25	24	42	35
Average		38	41	43,5	43,0	42,5

The development of e-Multimedia Animation (E-MMA) animation media is an innovative scientific effort in education with the main aim of overcoming learning difficulties that are often faced by students in the learning process, especially in the Engineering Materials course which focuses on sliding field material. The use of E-MMA as a tool has proven effective in improving students' mastery of concepts and problem-solving skills in learning and understanding sliding field material that has an abstract, complex, and dynamic nature [14]. Animation media is proven to have the potential to help a teacher and students during the learning process. The use of animation media in the form of E-MMA has several Advantages that make it an effective educational innovation:

i.   Clear visualization: By using animation media, abstract concepts in technical materials can be visualized clearly. Students can visually see how material structures behave in situations of shear fields, deformation processes, and interactions between particles or molecules. This helps students understand concepts better compared to relying solely on text explanations or static images.

ii. Interactive simulations: E-MMA allows students to engage in interactive simulations that allow them to delve deeper into sliding field concepts. Students can manipulate certain parameters, such as applied force, shear angle, or material type, and see how those changes affect response and behavior material. Thus, they can observe the impact of such parameter changes directly, reinforcing the necessary mastery of concepts.

iii. Dynamic material availability: E-MMA can be updated regularly to include the latest developments in sliding field material. By taking advantage of the dynamic nature of E-MMA, students can access the latest information on the latest technology, materials, or research relevant to the sliding field. This helps students stay in touch with the latest developments in materials engineering and encourages deep mastery.

Through the use of E-MMA animation media, it is hoped that DPTM Mechanical Engineering Education students can overcome the learning difficulties faced in learning abstract, complex, and dynamic material in the eye Engineering Materials lectures, especially sliding field materials. Increasing students' mastery and skills in these concepts are expected to increase. Thus, they can apply the knowledge better in the context of mechanical engineering. This is done because of how important this Sliding Field subject matter is in influencing the results of the reinforcement process and encouraging students to think critically, there are still difficulties in doing so [15], especially in the level of cognitive analysis or students' ability to analyze, provide evidence, identify reasons, and conclude from existing problems [16].

2. Shear Field Theory

2.1 Sliding Field Material Concept

Solid materials can be classified based on the regularity of atoms or ions arranged around each other. This refers to the arrangement of atoms or ions in the structure of the material. Crystalline materials have atoms or ions arranged in repeating or periodic patterns, which stretch across large atomic distances. In crystalline materials, the atoms have an orderly and well-organized arrangement. The regularity in the arrangement of atoms or ions in a crystalline material is very important. Crystallinity, that is, the degree of regularity in the crystal structure, affects the characteristics of the material. Properties such as hardness, thermal and electrical conductivity, clarity, mechanical strength, and optical properties can be affected by the degree of crystallinity. The higher the degree of crystal regularity, the more consistent and predictable the properties of the material. Thus, mastery of the order of atoms or ions in solid materials and their influence on crystallinity is essential in studying and understanding the properties and behavior of different materials [17-21].

In the field of mechanical engineering, the concept of atomic shear fields is one of the important concepts in understanding the properties and behavior of materials. Atomic shear plane refers to the shift in atomic or ionic layers that occurs when a material is subjected to a load or shear force. In crystalline materials, atoms or ions are arranged in a crystal structure with a repeating pattern. When the material experiences shear forces, the layer of atoms or ions in a certain shear plane will shift concerning the surrounding layer of atoms or ions. This shift occurs along the shear plane while maintaining periodic relationships between atoms or ions in the material (see Figure 1).
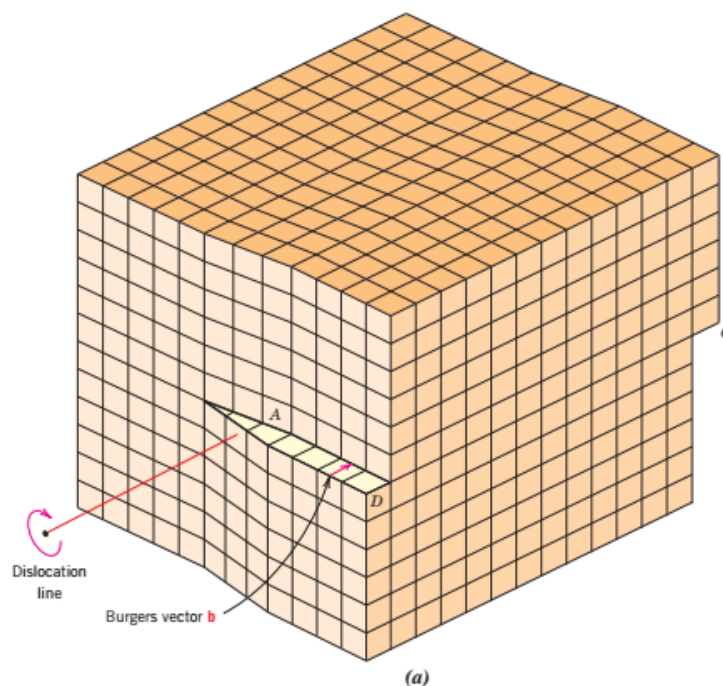

Fig. 1. A dislocated screw in a crystal. The dislocation of the screw is viewed from above. The longitudinal dislocation line AB line. The position of the atom above the designated slip plane by an open circle, which is below by a solid circle [27].

Atomic shear fields, including crystal dislocations (Figure 2), have an important role in determining the mechanical properties of materials. When there is a shift in the shear plane, including crystal dislocation, the material can undergo deformation or deformation. This deformation can affect the strength, hardness, ductility, and elasticity of the material. Mastery of atomic shear planes helps in studying material properties related to response to shear loads, such as shear strength, elasticity limits, and plastic deformation. In mechanical engineering practice, this mastery is essential for designing structures, components, and systems that can withstand loads and shear forces without experiencing failure or deformation undesirable.
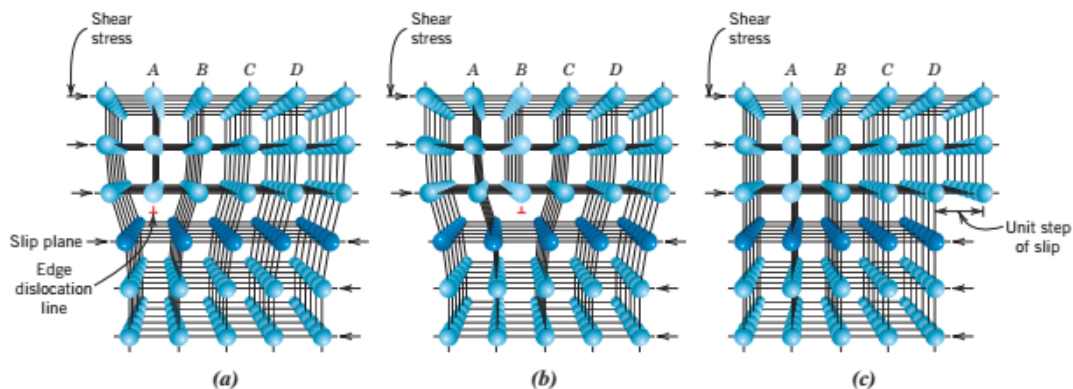

Fig. 2. Atomic rearrangement accompanies edge dislocation motion as it moves in response to applied shear stress. (a) The additional half of the atomic plane is labeled A. (b) The dislocation moves one atomic distance to the right when A is connected to the bottom of the plane B; in the process, the top B becomes an extra half-plane. (c) A step is formed on the surface of the crystal as the extra half plane comes out.

Plastic deformation occurs as a result of the movement of a large number of dislocations in the material. Dislocation of moving edges in response to shear stress applied in a direction perpendicular to its line, and the mechanics of this dislocation motion can be seen in Figure 2. Suppose we start with an additional half-plane of atoms originally referred to as plane A. When a shear stress is applied as shown in Figure 2a, plane A is pushed in the right direction, and this pushes the top of planes B, C, D, and so on in the same direction. If the applied shear stress is large enough, the interatomic bonds in plane B will be broken along the shear plane, and the top of plane B will be half-plane additional when field A is connected to the bottom half of field B (Figure 2b). This process is constantly repeated for the rest of the fields, so that the extra half of the plane, with separate steps, moves from left to right with a break the bonds are sequential and repetitive, and shift with interatomic distances over half-planes. Before and after the dislocation moves through a particular crystal region, the arrangement of atoms within that region remains orderly and perfect. Disruption of the lattice structure occurs only in part of that extra half of the plane. Ultimately, this extra half plane can emerge from the right surface of the crystal, forming an edge equal in width to the distance between atoms (Figure 2c).

The process by which plastic deformation occurs through the movement of dislocations is called slip. The dislocation line crosses the plane of crystallographic slip, as shown in Figure 3. Macroscopic plastic deformation results in permanent deformation due to dislocation movement, or slip, in response to applied shear stress (Figure 4).
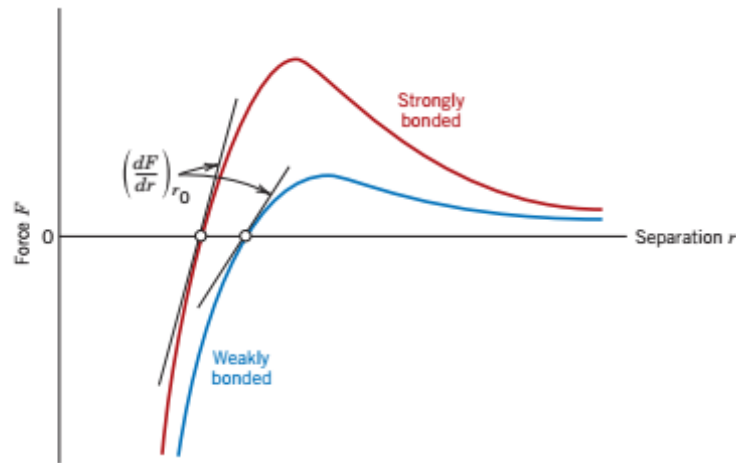
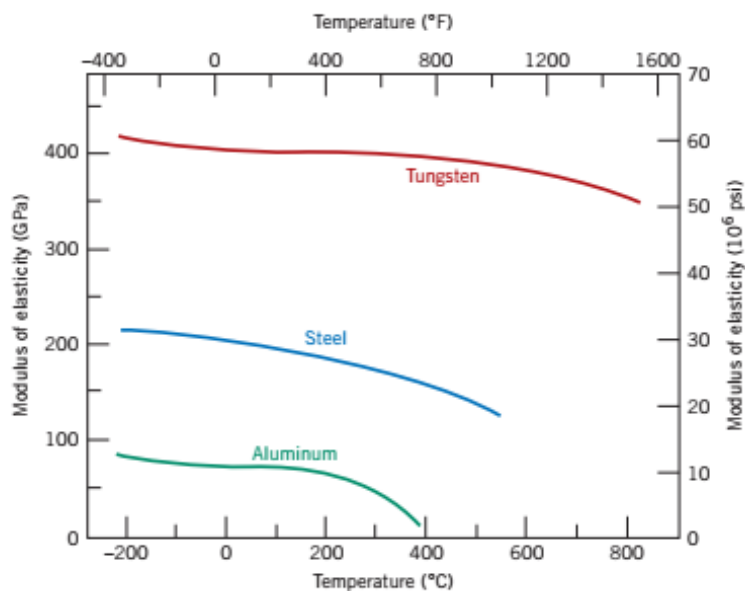**Fig. 3.** interatomic equilibrium separation r

Fig. 4. Plot of modulus of elasticity versus temperature for tungsten, steel, and aluminum. (Adapted from [26]. Reprinted with permission of John Wiley & Sons, Inc.)

In addition, mastery of atomic shear fields is also associated with phenomena such as slip, twinning, and recrystallization that occur in crystalline materials when deformed. The elastic behavior of the atomic shift effect plays an important role in understanding the material's response to the forces and deformations acting on it the magnitude of elasticity can be seen from the curve at the interatomic equilibrium separation explained that the force versus interatomic separation of weak and strong bonds of atoms, the modulus of temperature elasticity in each material will be different, for example, steel, tungsten, and aluminum are visible differences. The magnitude of the modulus of elasticity is proportional to the slope of each curve. Through research and development in this field, mechanical engineering can optimize the use of materials, design appropriate manufacturing processes, and develop new materials with superior properties and performance.

Considering the inherent relationship between shear plane materials and the use of materials and manufacturing processes, the use of atomic shear fields in mechanical engineering materials is

important in understanding mechanical properties and material response to shear loads, as well as contributing to the development of technology and innovation in mechanical engineering.

2.2 E-MMA Learning Media

Multimedia Animation (MMA) learning media for sliding plane material in engineering materials has been created by Callister and Rethwisch. However, the animation is still limited to the crystal structure in the form of unit cells, without containing the characteristics of each unit cell that precisely determine the mechanical properties material. That is, the learning media uses multimedia animation to describe the crystal structure in the sliding plane material. However, this animation only shows the general shape of the unit cells in the crystal structure, without incorporating the specific characteristics of each unit cell that affect the properties of material mechanics [3].

Each type of material has unique characteristics that are determined by the arrangement of atoms or ions in their unit cells. These characteristics include parameters such as crystal orientation, grain size, number and type of defects in the crystal structure, and so on. These characteristics directly affect the mechanical properties of the material, such as strength, hardness, ductility, and elasticity.

In the context of this explanation, it can be concluded that although the MMA learning media created by Callister and Rethwisch has provided a general description of crystal structure in the shear plane, it does not yet include the specific characteristics of unit cells that determine the mechanical properties of the material accurately. Therefore, there is potential to develop more complete and detailed animations to enrich the student learning experience in understanding the mechanical properties of materials related to the sliding field.

E-MMA stands for "Electronic Multimedia Animation," which is an electronic animation-based learning medium. This media is expected to meet the demands of 21st-century abilities in education, where learning must train the ability to think critically, solve problems, and be creative and innovative. This concept is in line with one of the indicators of the implementation of the 2013 curriculum, which aims to make students more productive, creative, innovative, effective, and happy in the process of learning [22].

Multimedia has changed the way of learning and teaching by providing great potential for the development of learning techniques. In the context of E-MMA, this media uses electronic animation to deliver learning materials interactively and interestingly. Multimedia allows the use of audio, visual, text, and interaction elements that allow for more interesting and effective learning. Through E-MMA, educators can develop diverse and innovative learning techniques to achieve maximum learning outcomes. The animations used in E-MMA can visualize abstract, complex, and dynamic concepts more clearly and in detail. In addition, interactivity in this medium can encourage active participation and involvement of students in the learning process.

By harnessing the power of multimedia in presenting engaging and interactive content, E-MMA can increase student motivation and interest in learning. This media can also facilitate the development of critical thinking, problem-solving, as well as creativity, and innovation skills through the use of more interactive, simulated learning methods, and visuals.

Overall, E-MMA as an electronic animation-based learning medium can provide a more interesting, interactive, and effective learning experience. By combining multimedia technology with modern educational goals, E-MMA can help create a learning environment that encourages students to be more productive, creative, innovative, effective, and happy to learn, following the demands of 21st-century abilities. Apart from the advantages of E-MMA, researchers were also impressed by the enthusiasm of students in welcoming E-MMA in learning Material Engineering, 97% of students

agreed to learn the Material Engineering course with E-MMA [23]. Students appreciate the quality of multimedia animation (E-MMA) which is good, attractive, easy to understand, and easy to operate. This media helps students learn and understand the subject matter of engineering materials more easily. Therefore, this multimedia animation is very important for students in the learning process [24]. This research shows how important the use of media is in improving student mastery [25].

3. Methodology
3.1 Research Methods Quasi-Experimental

This research uses a quantitative approach with quasi-experimental methods. This quasi-experimental research method allowed researchers to test the effects of E-MMA on shifts in microstructure and atomic properties in engineering materials. The study was conducted in two groups, namely the experimental group and the control group. The research design used was a nonequivalent control group design.

In this study design, measurements were taken twice. The first measurement was taken before both groups received treatment, and the second measurement was done after the treatment was given to both groups. It aims to compare the differences before and after treatment between the experimental group and the control group.

This research design was chosen because it did not allow random sample selection. Nonetheless, the nonequivalent control group design still provides an opportunity to gain an understanding of the effects of E-MMA on material microstructure shifts and atomic properties in materials engineering techniques. By involving experimental and control groups, researchers can test and compare the effect of treatment on conceptual understanding and problem-solving approaches in both groups.

Thus, this quasi-experimental research method with a nonequivalent control group design was chosen as an appropriate way to explore the effects of E-MMA on material shifts in microstructure and properties Atom in Engineering Materials Engineering, as well as to test students' conceptual mastery and problem-solving approaches.

Here are the steps of the quasi-experimental method:

i. Population and Sample Identification: The first step is to identify the relevant population for the study, e.g. DPTM Mechanical Engineering Education students. Next, from that population, researchers need to select a representative sample for the experimental group and the control group. Sample selection was not randomized in this study.

ii. Formation of Experimental Group and Control Group: After the sample is selected, the researcher divides the participants into two groups, namely the experimental group and the control group. The experimental group will receive treatment or treatment in the form of the use of E-MMA animation media, while the control group will not receive the treatment.

iii. Initial Data Collection: Before treatment, researchers conducted initial data collection on both groups. These initial data may be tests, questionnaires, or other relevant instruments to measure conceptual understanding and problem-solving approaches to microstructure shifting material and atomic properties.

iv. Treatment: After the initial data collection was completed, researchers gave treatment in the form of using E-MMA animation media to the experimental group. The control group still received no treatment and followed the usual learning.

v. Post-Treatment Data Collection: After the treatment was given, researchers collected data again in both groups. This data aims to see differences in conceptual understanding and problem-solving approaches after treatment.

vi. Data Analysis: After all the data is collected, the researcher performs data analysis to see the difference between the experimental group and the control group in terms of conceptual mastery and problem-solving approaches. Statistical analysis such as a mean difference test or hypothesis test can be used in this process.

vii. Interpretation of Results: Based on data analysis, researchers interpret research results to explain the effect of E-MMA on conceptual understanding and problem-solving approaches on microstructure shift material and atomic properties. These results can be used to inform the development of learning methods and improve mastery of the material for students.

viii. Conclusions and Suggestions: The final step is to conclude the research findings and provide suggestions for further research or development in the use of E-MMA animation media in mechanical engineering education.

3.2 Data Collection Methods

The selection of data collection sites at the location is based on research objectives intended for prospective teachers of SMK production machinery study programs with materials and curricula as listed in JPTM FPTK UPI. This is the reason for purposive sampling, namely by selecting samples that match the criteria set. In addition, the reason for purposive sampling is also adjusted to the R&D method used, which focuses on product development rather than application research. Another main reason is to provide benefits with the creation of animated multimedia-based e-books, especially for students of the Department of Mechanical Engineering Education as prospective vocational teachers, as well as for the general public.

The population of this study is all students of the Department of Mechanical Engineering Education at FPTK UPI. The samples used are in the form of validation test samples, namely students of the Department of Mechanical Engineering Education from all packages, including Automotive Packages, Production Packages, and Design, as well as Refrigeration and Air Conditioning Packages that are or have contracted Material Engineering courses. The instruments used in this study include tests, rubrics, and questionnaires. Data collection is carried out in four stages, namely preliminary studies, initial product design and development, trials, and product validation tests and dissemination. Each stage of research requires appropriate data collection techniques and tools.

Data analysis techniques in this study generally use descriptive analysis. Descriptive analysis is performed to describe data from questionnaires, observations, and rubrics. The analysis was conducted qualitatively by explaining information based on certain categories, as well as quantitatively by using percentages and averages of learning outcome improvement data (N-gain).

There are three stages in this study, namely Pretest, Treatment, and Posttest. The stages carried out in this study can be described as follows:

i. Pretest: Before applying the treatment, students from both groups were given a test to measure mastery of concepts and problem-solving skills in the Phase Diagram subject matter.

ii. Treatment: In the experimental group, E-MMA was applied as a learning medium, while the control group used conventional images as a learning medium.

iii.   Posttest: The final test is conducted to measure the improvement of student's mastery of concepts and problem-solving abilities after the implementation of E-MMA in the learning process of Phase Diagram subjects. Both the control group and the experimental group were given tests to compare the results.

The validation test in this study used a nonequivalent control group design. This study involved two groups, namely the experimental group and the control group. Both groups were given pre-tests to evaluate the initial differences between them. Table 3 shows the design patterns used in this study.

Table 3
Nonequivalent control group design

Group	Pre-test	Treatment	Post-test
Experiment	T_{E1}	X	T_{E2}
Control	T_{K1}	And	T_{K2}

where T_{E1}/T_{K1} is Initial test given to students, X is Learning by using *E-MMA*, Y is Learning with the use of Images and *Handouts*, T_{E2}/T_{K2} is Final test given to students.

The two-mean difference test from two tol was carried out to determine whether between the experimental group and the control group, there was a difference in N-Gain (gain crystallization) (Eq. (1)).

$$(N - Gain) \quad = \frac{\%\ actual\ gain}{\%\ potential\ gain} = \frac{\%\ skor\ postes - \%\ skor\ pretes}{100 - \%\ skor\ pretes} \tag{1}$$

In this study, descriptive analysis was carried out using the N-Gain method by referring to the N-Gain criteria according to Hake. The criteria include: 1) High gain ("high-gain") if N-Gain > 0.7; 2) Moderate increase ("medium-gain") if 0.7 ≥ N-Gain ≥ 0.3; and 3) Low increase ("low-gain") if N-Gain < 0.3. In addition, there are also other eligibility criteria in the descriptive analysis, which is to achieve 75% of the ideal score.

4. Results and Discussion

Based on the analysis of questionnaires given to 41 students in the experimental class, the following results were obtained: 0.3% strongly disagree, 2.2% disagree, 65.3% agree, and 31.7% strongly agree with the use of E-MMA in learning technical materials. This shows that most students (65.3% agree and 31.7% strongly agree) find E-MMA more interesting and facilitate mastery of the material. Overall, 97.0% of students responded positively by agreeing or strongly agreeing with the use of E-MMA. Students rate E-MMA as a good learning resource, interesting, easy to understand, easy to operate, and helpful in understanding the subject matter. Preliminary studies also indicate that students want to develop material that is easy to obtain, interesting, and not boring, while the learning resources and media that are generally used are books. Therefore, the use of E-MMA is considered a fresh and better alternative. Students also believe that E-MMA can increase their motivation and confidence in mastering the material better.

4.1 Results of Mastering the Sliding Field Concept

The results of calculating data for mastery of the concept of atomic shear fields in the control group showed the following (Table 4; Figure 5): (a) pretest score: 15.00 as the lowest score, 50.00 as the highest score, and an average score of 26.94, all of which are in the initial ability category with

unpassed grades ; (b) posttest score: 25.00 as the lowest score in the unpassed grade category, 60.00 as the highest score in the sufficient grade/C category, and the average score of 38.23 who are in the ability category with unpassed grades ; (c) N-gain percentage: 6.67 as the lowest percentage in the low category, 38.46 as the highest percentage in the medium category, and an average percentage of 15.52 in the in the low category.

Meanwhile, in the experimental group, the following results were obtained: (a) a pretest score: of 5.00 as the lowest score, 45.00 as the highest score, and an average score of 23.25, all of which are in the initial ability category with unpassed grades ; (b) posttest score: 55.00 as the lowest score in the less grade/D category, 85.00 as the highest score in the near-privileged score category/A-, and an average score of 71.78 which is in the fairly good grade/B- category; (c) N-gain percentage: 38.46 as the lowest percentage in the medium category, 77.78 as the highest percentage in the high category, and the average percentage 62.82 which is in the medium category.

In increasing mastery of the concept of atomic shear plane, the use of MMA provides a significant increase with an average N-gain percentage of 62.82%, which is in the medium category. This is a higher increase compared to the use of image media which only achieved an average N-gain percentage of 15.52%, which is in the low category. Thus, it can be concluded that the use of MMA in studying the crystal structure of atoms effectively increases mastery of the concept to reach the medium category.

Table 4
Results of *pre-test, post-test,* and *N-Gain* calculations mastering the concept of atomic shear plane

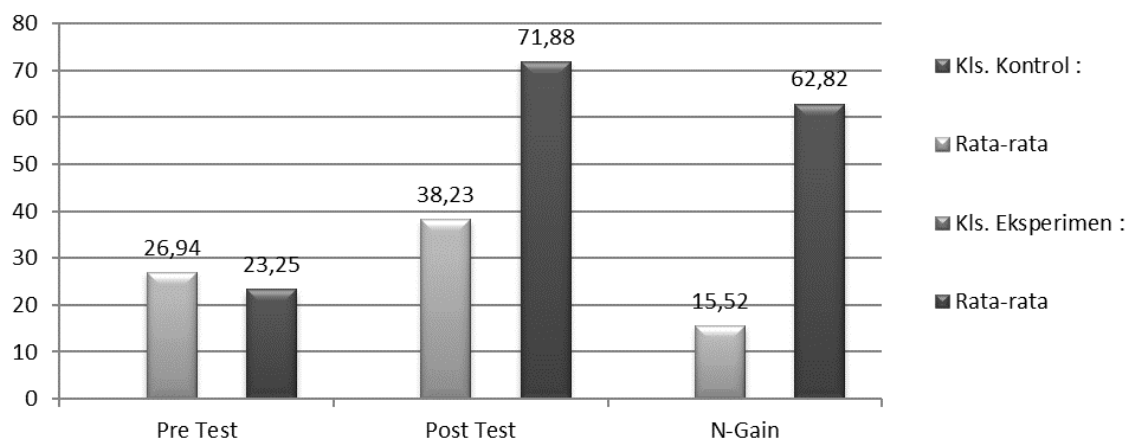| Data	Shoes	Class	
		Control	Experiment
Pre-Test	Highest	50.00	45.00
	Lowest	15.00	5.00
	Average	26.94	23.25
Post Test	Highest	60.00	85.00
	Lowest	25.00	55.00
	Average	38.23	71.88
N-Gain (%)	Highest	38.46	77.78
	Lowest	6.67	38.46
	Average	15.52	62.82

Fig. 5. Pre-test, post-test, and N-Gain calculation results from mastery of the atomic shear plane concept

4.2 Results of Mastery of Sliding Field Skills

In data analysis for solving atomic shear plane problems in the control group, the following results were obtained (Table 5; Figure 6): (a) a pretest score: of 0.00 as the lowest score, 40.00 as the highest score, and an average score of 11.82, all of which are in the initial ability category with unpassed scores ; (b) posttest score: 10.00 as the lowest score in the unpassed score category, 60.00 as the highest score in the sufficient grade/C category, and the average score 25.91 who are still in the category of unpassed grades ; (c) N-gain percentage: 10.00 as the lowest percentage in the low category, 33.33 as the highest percentage in the medium category, and an average percentage of 15.98 in the in the low category.

Meanwhile, in the experimental group, the following results were obtained: (a) a pretest score: of 0.00 as the lowest score, 40.00 as the highest score, and the average score of 12.73, all of which are in the initial ability category with unpassed grades ; (b) Posttest score: 70.00 as the lowest score in the good enough grade/B- category, 100.00 as the highest score in the excellent score category/A, and an average score of 82.27 which is in the very good grade category/B+; (c) N-gain percentage: 70.00 as the lowest percentage in the medium category, 100.00 as the highest percentage in the high category, and the average percentage 79.72 which is in the high category.

In improving atomic shear plane problem-solving skills, the use of MMA provides a significant increase with an average N-gain percentage of 79.72%, which is in the high category. This is a higher increase compared to the use of image media which only achieved an average N-gain percentage of 15.98%, which is in the low category. Thus, it can be concluded that the use of MMA in studying atomic shear fields effectively improves problem-solving skills to reach the high category.

Table 5
Results of pre-test, post-test, and N-Gain calculations of atomic shear plane troubleshooting

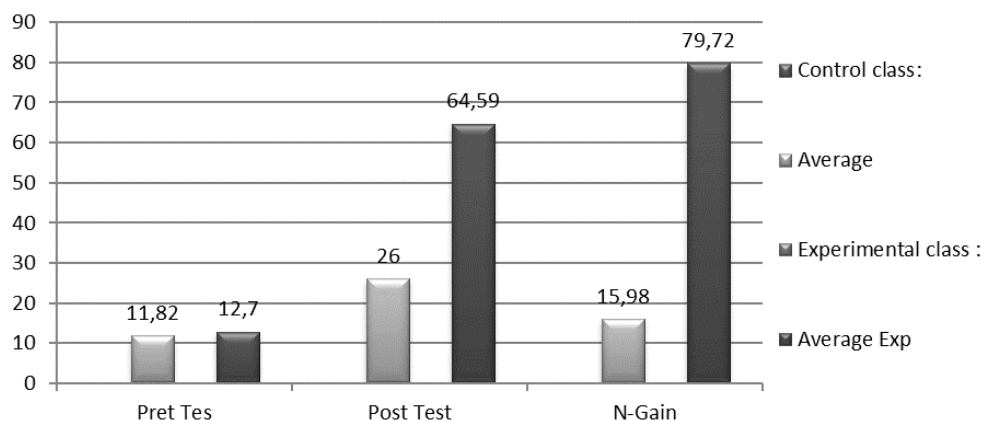| Data	Shoes	Class	
		Control	Experiment
Pre-Test	Highest	40.00	40.00
	Lowest	0.00	0.00
	Average	11.82	12.73
Post Test	Highest	60.00	100.00
	Lowest	10.00	70.00
	Average	25.91	82.27
N-Gain (%)	Highest	33.33	100.00
	Lowest	10.00	70.00
	Average	15.98	79.72

Fig. 6. Pre-test, post-test, and N-Gain calculations for atomic shear plane troubleshooting

Based on the results of calculating data for mastery of the concept of atomic shear fields in the control group and experimental group, the following conclusions can be drawn:
In the control group:

i) The pretest score is in the range of 15.00 to 50.00 with an average score of 26.94, which indicates that the initial ability in the grade category has not passed.
ii) Posttest scores are in the range of 25.00 to 60.00 with an average score of 38.23, which is also still in the ability category with unpassed scores.
iii) The N-gain percentage is in the range of 6.67 to 38.46 with an average percentage of 15.52, which is in the low category.

In the experimental group:

i) Pretest scores are in the range of 5.00 to 45.00 with an average score of 23.25, indicating initial ability in the grade category has not passed.
ii) Posttest scores are in the range of 55.00 to 85.00 with an average score of 71.78, which is in the category of quite good scores.
iii) The N-gain percentage is in the range of 38.46 to 77.78 with an average percentage of 62.82, which is in the medium category.

From these comparisons, it can be concluded that the use of MMA in atomic shear plane learning significantly increases mastery of concepts with a higher percentage of N-gain compared to the use of image media. This increase reached the medium category, while the use of image media only reached the low category. Therefore, it can be said that the use of MMA is effective in increasing mastery of concepts in atomic shear plane matter. Based on data analysis for solving the atomic shear plane problem in the control group and experimental group, the following conclusions can be drawn:
In the control group:

i) The pretest score is in the range of 0.00 to 40.00 with an average score of 11.82, which indicates that the initial ability in the grade category has not passed.
ii) Posttest scores are in the range of 10.00 to 60.00 with an average score of 25.91, which is also still in the unpassed score category.

iii)   The N-gain percentage is in the range of 10.00 to 33.33 with an average percentage of 15.98, which is in the low category.

In the experimental group:

i)   Pretest scores are in the range of 0.00 to 40.00 with an average score of 12.73, indicating initial ability in the unpassed grade category.

ii)   Posttest scores are in the range of 70.00 to 100.00 with an average score of 82.27, which is in the very good score category.

iii)   The N-gain percentage is in the range of 70.00 to 100.00 with an average percentage of 79.72, which is in the high category.

From these comparisons, it can be concluded that the use of MMA in atomic shear plane learning significantly improves problem-solving skills with a higher percentage of N-gain compared to with the use of image media. This increase reached the high category, while the use of image media only reached the low category. Therefore, it can be concluded that the use of MMA is effective in improving problem-solving skills on atomic shear plane matter to reach the high category. In the title of the journal "Increasing Mastery of Concepts and Development of Student Skills in Understanding the Concept of Sliding Fields Using E-MMA in the Mechanical Engineering Material Course," there are several interesting author's notes, namely:

i)   Focus on improving mastery of concepts: The author emphasizes the importance of mastery of concepts in studying atomic shear planes. This shows that this study seeks to improve students' mastery of concepts in the topic.

ii)   Student skill development: In addition to mastery of concepts, the author also focuses on developing students' skills in understanding the concept of atomic shear planes. This shows that this research does not only focus on theoretical aspects but also deep application and mastery.

iii)   Use of E-MMA: The author used E-MMA (Electronically Modified Multimedia Animation) as a learning tool in this study. The use of multimedia technology provides an interactive and visual approach to teaching the concept of atomic sliding planes, which can improve student mastery.

iv)   Application to the Mechanical Engineering Materials course: This research was conducted in the Mechanical Engineering Materials course, which shows its relevance and direct application in the context of mechanical engineering education. This adds to the practical and applicative value of the research.

v)   Research objectives: Although not directly mentioned in the title, authors may mention their research objectives in the article. Information about the purpose of the study can provide further insight into the intentions and direction of the research conducted.

These notes provide an initial overview of the issues addressed in the journal, the approach used, and the research objectives to be achieved. This helps readers to understand the context and relevance of the research before further reading the contents of the journal.

5. Conclusions

As we draw the curtain on this scientific narrative, let us take the final steps in this meaningful journey of exploration. In this chapter, we will distill the intriguing details unveiled, unravel the common thread of this research, and open a window to glimpse the potential directions for future inquiry. This conclusion not only marks the end of a study but also serves as the commencement of a broader and deeper odyssey into knowledge:

i) E-MMA Exhibits Significant Improvement in Conceptual Mastery: The study disclosed a notable advancement in understanding concepts, evident in an impressive average surge of 62.82% in concept mastery among students exposed to E-MMA. This is in stark contrast to the meager 15.52% increase observed in the control group employing traditional visual aids.

ii) Addressing Specific Learning Hurdles: The investigation identified prevalent challenges among students, particularly in areas like phase diagrams (68.8%) and the movement of atoms within crystal structures (25.0%). E-MMA demonstrated effectiveness in alleviating these challenges, presenting a tailored solution for specific learning obstacles.

iii) Effective Educational Tool for Technical Disciplines: The results emphasize the appropriateness of E-MMA as an educational tool, particularly in technical fields like materials engineering. The approach not only tackled common learning barriers but also facilitated a substantial enhancement in overall comprehension.

iv) Comprehensive Learning Improvement: Beyond mastering concepts, E-MMA showcased its efficacy in enhancing problem-solving skills. The experimental group displayed a noteworthy 79.72% average improvement in problem-solving abilities, in contrast to a modest 15.98% in the control group, indicating a comprehensive enhancement in students' learning experiences.

Contributing to Overcoming Challenges Related to Microstructures: In summary, the research establishes E-MMA as a valuable asset for students grappling with challenges related to microstructures in materials engineering. The method's success in improving both conceptual understanding and problem-solving skills underscores its potential to address the complexities linked to atomic shifts in microstructural materials.

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