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Virtual Microscopic Simulation (VMS) of Light-Wave to Enhance the Student's Understanding Level

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Abstract

This study aims to develop a valid Virtual Microscopic Simulation (VMS) media used in light wave learning and evaluate the use of VMS media in increasing students' level of understanding. The research method used in this research is research and development using the ADDIE model. The sample in this study consisted of 35 students at one of the universities in central Jakarta, Indonesia. The results showed that the development of VMS on the light wave material, when implemented, the gain test calculation increased the level of students' understanding of 0.56 in the medium category. The results of the level of student understanding obtained complete understanding data by 52% of students understanding partly, 42% of students understanding incorrectly, and 3% of students not understanding. This shows that using VMS media on light wave material can enhance student understanding.

Keywords: Virtual Microscopic Simulation (VMS), light wave, student's understanding level

INTRODUCTION

Learning physics in class emphasizes students memorizing concepts without being based on harmony between the facts students encounter and the concepts they have (Baran, Maskan & Yasar 2018; Kersting, Schrocker & Papantoniou 2021). This causes some students still experience difficulties in understanding concepts and principles, especially in understanding physics material related to abstract physical phenomena (Ince 2018; Ang, Cao & Ang 2021). During learning, students fail to imagine and visualize how the microstate of a phenomenon cannot be observed with the naked eye (Kuby & Fraser 2022). One of the physics materials with abstract physical phenomena is light waves. Light is energy in the form of waves because the light is radiant energy. Radian energy in light comes from the sun as a source of light on earth (Xu 2019). This energy is composed of electrical and magnetic energy, known as electromagnetic energy (Maamer et al. 2019). In physics, light is electromagnetic radiation with visible or invisible wavelengths. Visible light is a portion of the spectrum with a wavelength of approximately 380 nm to 800 nm in the air (Ghribi et al. 2022). Visible light as electromagnetic radiation is the part of the electromagnetic wave spectrum that can be detected by the human eye (Ghribi et al. 2022). As with waves in general, light as a wave has several characteristics, such as interference and light diffraction. Light interference occurs when two or more waves overlap in the same space. Interference is when two waves travel in the same direction and in the same space (Madan et al. 2019).

When this phenomenon occurs, the total waveform at any point at any time is determined by the superposition principle. The superposition principle states that when two or more waves overlap, the resultant shift at any point and at any moment can be found by adding the instantaneous shifts produced at that point by the individual waves if the waves were present alone (Yang et al. 2020). Thus, in principle, it can be said that the interference of light waves arises due to the superposition of two or more waves which creates new waves. Meanwhile, diffraction is the spreading or deflection of a wave when it passes through an obstacle. Diffraction is waves that spread as they propagate, and when they encounter an obstacle, these waves turn around and enter the following area (Violante et al. 2021). Diffraction occurs when an obstacle partially obscures the wavefront, and the unobstructed portion of the wavefront is deflected behind the obstacle. This deflection of the wavefront is called diffraction; the magnitude of diffraction depends on the wavelength and the size of the obstacle. Based on these characteristics, light is a difficult concept to understand completely.

Learning light waves in class directs students to solve problems using complex mathematics; too much material; rely on abstract and complex textbooks; and for real completion, laboratory activities are needed (Kapilan, Vidhya & Gao 2021). This causes students to experience misunderstandings in learning a physics concept. Misunderstanding occurs due to the inability of students to correctly recognize the double slit interference pattern and diffraction lattice patterns in monochromatic light, the lack of students' ability to interpret interference and diffraction in terms of the basic wave model and their lack of understanding of de Broglie wavelengths (Dawoodbhoy, Shapiro & Rindler-Daller 2021). The solution that can be used to minimize misunderstandings when studying light waves is to use virtual simulation media. Computer simulations offer ideal, dynamic, and visual representations of physical phenomena and experiments that are dangerous, expensive, or impossible in school laboratories (Sypsas & Kalles 2018). Virtual Reality Technology for Physics Learning media (Budi et al. 2021). Computer simulations are designed to effectively change students' conceptualizations (Codding et al. 2021). Virtual simulation can make it easier for students to process new scientific conceptions in the minds of students because visual depictions of abstract and microscopic phenomena assist it. Students will more easily understand it and thus erroneous conceptions embedded in their minds will be easier to get rid of and replaced with a scientific conception. The advantage of simulation when compared to other learning media, among others, is as an alternative to overcoming incomplete facilities and materials; (2) can visualize complex phenomena or experimental forms to help students improve their abilities and skills in the process of solving problems; (3) overcome the limitations of space, time, tools and materials; and (4) become a tool that helps students in strengthening student understanding; and (5) can present a simplified external visualization of phenomena that cannot be observed easily, and direct students to think about the interconnection between theory and its visualization (Budi & Muliyati 2018; Dewi et al. 2020).

Several research results have been found in literary studies to increase students' understanding of light wave material, including by proposing the use of Virtual Microscopic Simulation (VMS) media as a medium that students can use in visualizing abstract phenomena to minimize increasing conceptual understanding of the student. Virtual Microscopic Simulation as a demonstration to visually visualize the physical mechanism model of an object from an abstract phenomenon microscopic phenomenon, which is made possible by using computer-assisted teaching aids (Darman et al. 2019; Bermúdez & Romero 2020). Virtual Microscopic Simulation models an abstract object that becomes more real (Wibowo et al. 2019). Thus, it can be synthesized that Virtual Microscopic Simulation is a tool used to visually imitate an abstract phenomenon to make it look more real with the help of a computer (Wibowo et al. 2017).

Based on this background, it is the basis for the need to fulfill the needs of learning media to improve students' conceptual understanding of learning physics. Thus, it is necessary to develop Virtual Microscopic Simulation media as a learning medium for light wave material. After product development is complete, a VMS usage review will be carried out on the level of student understanding on indicators of giving examples, classifying, drawing inferences, and explaining. Therefore, this study aims to developing a valid Virtual Microscopic Simulation (VMS) media used in light wave learning and evaluating the use of VMS media in increasing students of level of understanding for media learning physics on light waves to increase students' level of understanding on indicators of giving examples, classifying, drawing inferences, and explaining in the universities in central Jakarta, Indonesia.

METHODS

The method used in this research with ADDIE model (Artman 2020) for the development of Virtual Microscopic Simulation (VMS) of Light Waves to Enhance the Level of Understanding of Students'. The sample in this study amounted to 35 students at one of the universities in central Jakarta, Indonesia. The scheme for developing the ADDIE model can be seen in FIGURE 1.

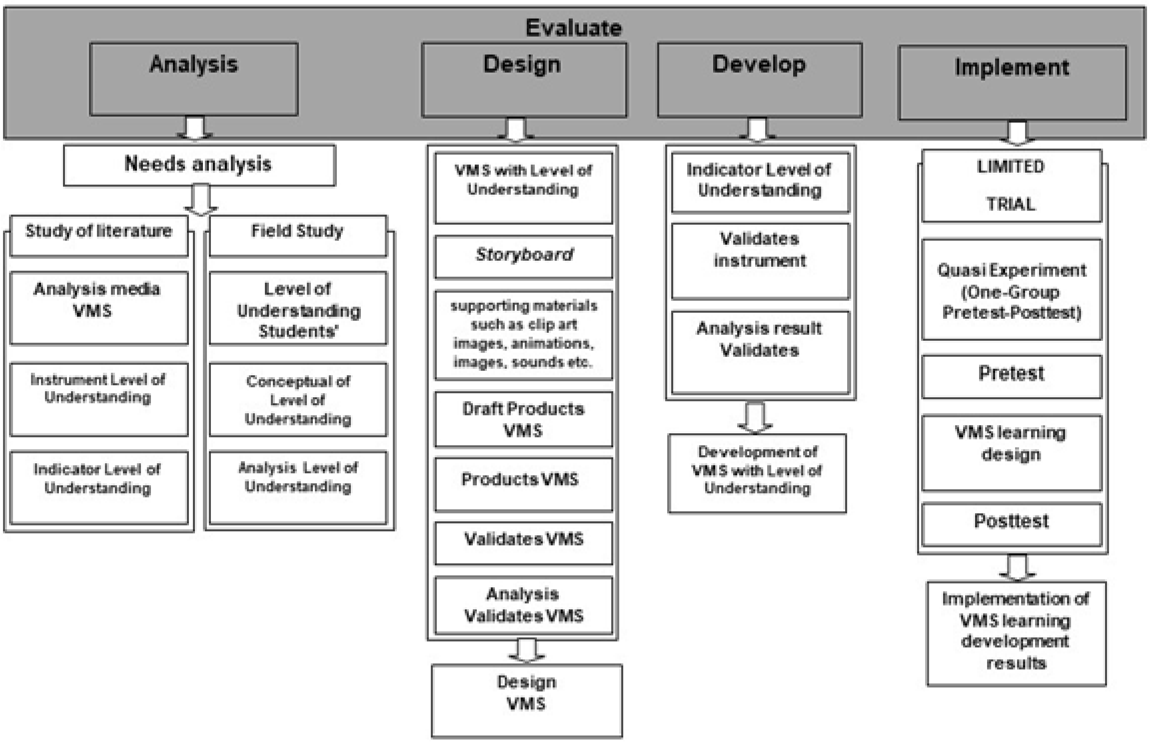

FIGURE 1. Virtual Microscopic Simulation (VMS) development method.

FIGURE 1, Providing information about Analyze is the first stage of the ADDIE model, which is carried out to determine the needs of physics learning media at universities. Next, analyze the results of studies on the development and use of computer simulations in physics learning. The scientific articles used were obtained from Computers and Education, Asia-Pacific Forum on Science Learning and Teaching, Science Education, IOP Conf. Series, Journal of Physics, Procedia Technology, Proceedings of the SPIE, Physical Review Physics Education Research, Science Direct, American Scientific Publishers, Instructional Science, Research in Higher Educational Journal, American Journal Physics, American Physical Society, and several other sources. The search process is limited to journal articles published between 2000 and 2020. Based on the search process from the source database provider, 30 journal articles were found.

The design in this study consists of designing media designs using VMS storyboards, selecting software using Adobe Animate to develop VMS media, and designing instruments to test students' understanding levels in the form of grids. This study consists of developing VMS media. Then validation is carried out by experts. After the VMS media has been validated, the media is revised again according to the criticisms and suggestions were given by experts. In addition, at this stage, instrument development activities were also carried out regarding the level of student understanding. The instrument questions that were compiled were then validated by instrument experts. After the questions are validated, the questions are revised according to the suggestions and criticisms given by the experts. The implementation phase was carried out with field trials on teachers and students at a university in Jakarta, Indonesia. The Evaluate stage of ADDIE model is the evaluation stage. The evaluation in this study is in the form of a formative evaluation to revise each stage of the ADDIE model, starting from the analysis stage to implementation and summative evaluation.

Processing of level Understanding tests and understanding models to identify levels (levels) and models of understanding will be constructed to test the achievement of understanding of physics teaching materials in the form of an open description test. For each question, it will consist of several items (sections) of questions consisting of items about applying (A), using (B), exemplifying (C) and defining (D) from theoretical knowledge. In the first question item, examples of cases that occur in everyday life are presented, and students are asked to explain the case or event (Item A), the second question item, students are asked to determine the laws of physics related to the case or event in item first question (Item B) and in the third question item, students are asked to name examples of cases or other events related to the laws of physics in the second item (Item C). In the fourth question item, students are asked to define the laws of physics in the second question item (Item D) see Appendix (Calik & Ayas 2005; Dewi et al. 2020)). Then calculate the percentage of the number of students for each level of understanding using the categorization guide in TABLE 2, Percentage calculation:

$$\%\text{ Level of Understanding} = \frac{\text{Number of students at each level of Understanding}}{\text{The total Number of students}} \times 100\%$$

To find out the criteria for the percentage of students at each Understanding Level, the guidelines shown in TABLE 1 are used.

TABLE 1. Criteria for the Percentage of Students at Each Level of Understanding

Total of Student (%)	Criteria
JM = 0	None of the students
0 < JM ≤ 25	Few students
25 < JM ≤ 50	Almost half
JM = 50	Half
50 < JM ≤ 75	Most students
75 < JM ≤ 100	Almost all students
JM = 100	All students

The categorization of Level of Understanding criteria based on TABLE 1 is divided into 7 criteria, namely none of the students, few students, almost half, half, most students, almost all students, all students (Dewi et al. 2020) and student answers are checked with a rubric on the indicator contained in TABLE 2 according to Characteristics of Student Answers.

RESULTS AND DISCUSSION

Virtual Microscopic Simulation (VMS)

Virtual Microscopic Simulation (VMS) is a tool used to visually imitate an abstract phenomenon to make it look more real with the help of a computer. VMS was developed using Adobe Animate software. VMS on light wave material consists of two topics: interference and light diffraction. The developed VMS can display simulations with microscopic views on both interference and diffraction topics. This page contains navigation buttons in the form of the back button, user manual button and exit button, light interference menu, single slit diffraction menu, diffraction grid menu, and profile menu. The display of the main menu page contained in the VMS media can be seen in FIGURE 2.

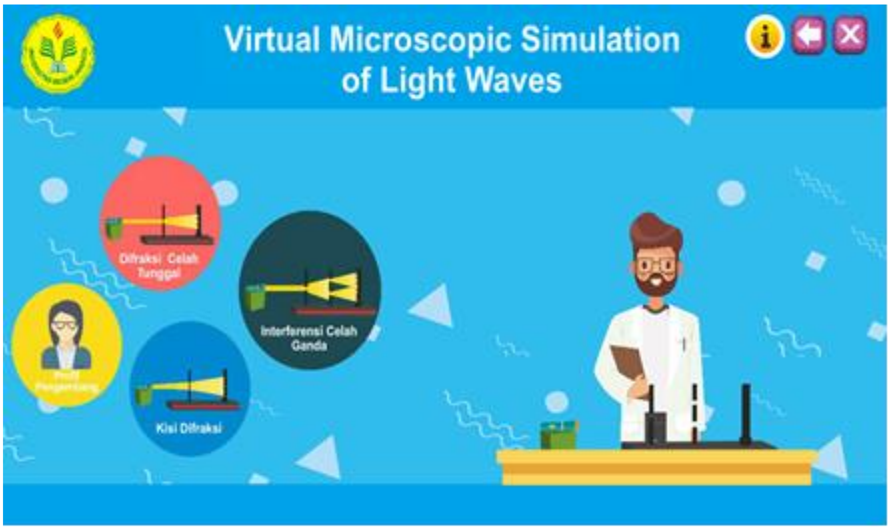

FIGURE 2. VMS main menu page

FIGURE 2 is the main menu display of the light wave concept VMS with four main button components, single slit diffraction, double-slit interference, and grating in fractions. Next, the microscopic simulation view of the VMS on light wave material can be seen in FIGURE 3.

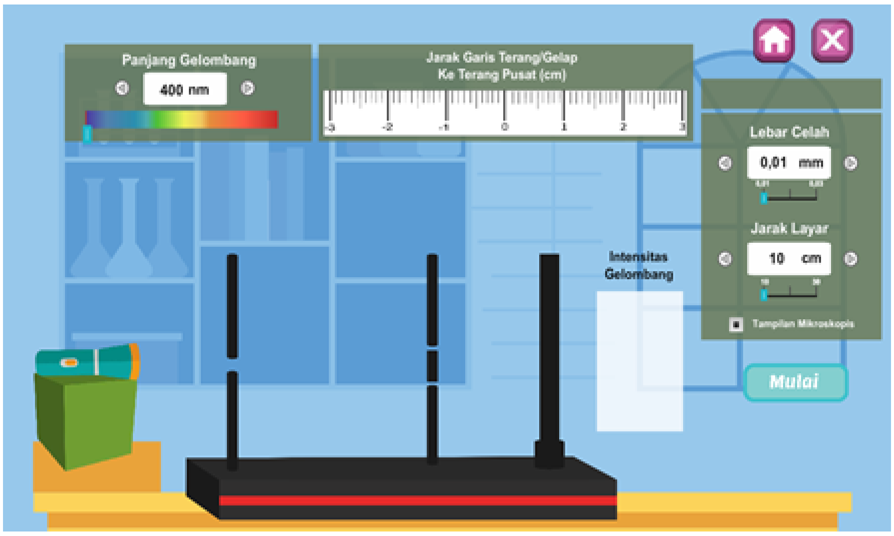

FIGURE 3. Microscopic view of VMS on light interference and diffraction material

FIGURE 3, This page contains navigation buttons and the main menu consisting of the material menu and the simulation menu. The material menu contains materials or supporting information on double-slit interference, while the simulation contains virtual simulations with microscopic and non-microscopic views of the concept of double-slit interference. Virtual simulation describes or visualizes how light rays propagate through two narrow slits so that an interference pattern is formed on the screen. The beam of rays is perpendicular to the lattice, and a converging lens is used to collect the rays to the desired point p on the screen (Yu et al. 2022). The intensity distribution observed on the screen is a combination of interference and diffraction effects. Each slit produces diffraction as described previously, and the previously diffracted rays interfere on the screen producing the final pattern. The interference pattern is described in an arbitrary α direction before reaching the point of interest. Each light comes from a different slit. For two different slits, the path difference that occurs is d sin α. Thus the general requirements for the interference pattern are as follows: D sin = n λ (n = 1,2,3,...) (Davydov & Zlydneva 2021).

These requirements can be expressed to determine the wavelength by measuring α if the lattice constant d is known as an integer, and n represents the order of diffraction. If the incoming wave on the lattice consists of several wavelengths, each will deviate or form a maximum in a different direction. Except for n=0 which occurs in the direction of = 0. A slit exposed to light from the front will project a bright image of the same shape as the slit behind it. But besides that, other bright shadows were also formed from the gap next to the original shadow, and the closer to the edge, the less bright it was. So, it's as if the light rays passing through the gap are being bent or diffracted in a sideways direction. Such a diffraction phenomenon is none other than the interference of light, electromagnetic wave rays from each part of the wave field as a source of light waves.

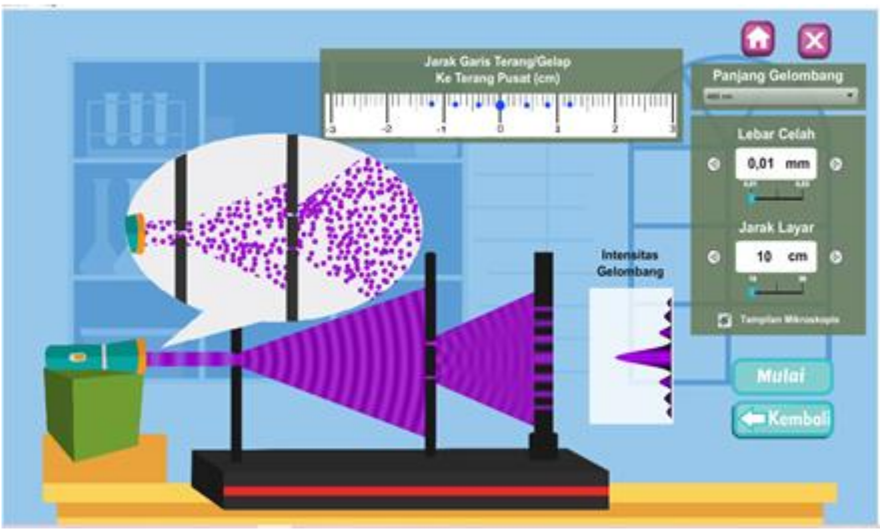

FIGURE 4. Microscopic view of VMS on light interference and diffraction material

FIGURE 4 presents a microscopic simulation of the double-slit interference, single-slit diffraction, and diffraction grating processes in VMS media. There are 2 variables in the experiment: the dependent variable and the independent variable. The dependent variable in this simulation is data that the user can set. The user can vary the screen distance and gap width. The independent variable is the data that will be generated from the simulation, such as the distance between the light and dark patterns on the screen. The process of forming interference and diffraction patterns is shown by the propagation of light waves through the slit. The range of experimental data obtained from the simulation, among others: (1) Wavelength: 400 nm, 480 nm, 500 nm, 580 nm, 600 nm and 680 nm (2) Slit width: 0.01 mm to 0.03 mm, (3) Screen distance: 10 cm to. 30 cm.

The media development that has been completed is then validated by experts. The VMS media validation test was assessed by 1 expert lecturer from the Department of Physics, FMIPA, State University of Jakarta, who had a background in accordance with the developed material and 2 expert lecturers from the Department of Physics, FMIPA, State University of Jakarta, who had a background in accordance with the learning media developed. Media validation by material experts is carried out to obtain information, criticism, and suggestions so that VMS media becomes a quality product in terms of material, linguistic, and learning aspects. The assessment is given through a validation test instrument sheet by a material expert. The validation test instrument sheet contains 20 questions including material that supports the achievement of learning objectives, the material has the truth of scientific physics and the presentation of the material. The VMS validation results by material experts with an average score of 87%. Based on the Likert scale criteria, the interpretation is that the VMS in light wave material is in the Very Good criteria. This shows that the VMS media on light wave material is valid to be used as a learning medium. Assessment is given through validation test instrument sheets by media experts. The validation test instrument sheet contains 33 questions covering aspects of display design, software, and quality of VMS usage. The results of VMS validation data by media experts with an average score of 81.5% for expert I and 80% for expert II. Based on the Likert scale criteria, the interpretation is that the VMS in light wave material is in the Good criteria. This shows that the VMS media on light wave material is valid to be used as a learning medium.

Good learning media is seen not only from the attractive appearance of the media but also from the material presented on the VMS media. An attractive VMS display with images, text and experimental simulations can support an understanding of the material (Makransky et al. 2021; Wibowo et al. 2017). Simulation with microscopy can help students build relationships between material and physical phenomena that occur in life (Darman et al. 2019; Fuchs, Corni & Pahl 2021). The microscopic display on the VMS media serves to visualize the real light propagation when it passes through a narrow slit so that an interference and light diffraction pattern is formed on the screen. This visualization helps students increase their understanding of the concepts of interference and light diffraction.

Level of Understanding with VMS Concept Light Wave

VMS development products that have been validated with valid criteria are then tested on a limited scale so that the effectiveness and satisfaction of using VMS can be determined. This study used the gain test to determine the increase in students' understanding level after using VMS media in light wave learning. The data used for the gain test were obtained from the results of the pretest and posttest given to students before and after using the VMS media. The pretest is carried out at the beginning of learning light waves. After the pretest activities, students carry out learning activities using VMS media. From the pretest activities, calculations are then carried out to determine the level of student understanding (Dewi et al. 2020) before using the VMS media. The level of student understanding based on the pretest can be seen in TABLE 2.

TABLE 2. Level of understanding student on the pretest.

Level of Understanding	Characteristics of Student Answers	Concept Labels			
		1	2	3	4
		Σ %	Σ %	Σ %	Σ %
[4] Complete Understanding (CU)	Correctly answer all the questions on a question	0(0)	0(0)	1(3)	0(0)
[3] Partial Understanding (PU)	Correctly answer some of the questions on a question	7(52)	4(42)	7(21)	2(6)
[2] Misconception (M)	Answer with all the questions on a question, but the answer is not clear, or the answer is wrong	14(42)	15(45)	13(39)	10(30)
[1] Not Understanding (NU)	Answering all the questions on a question but the answers given are not appropriate (irrelevant) to the question	1(3)	3(9)	6(18)	7(21)
[0] No Answer (NA)	Does not provide answers to all questions on a question item	1(3)	1(3)	6(18)	14(42)

Information:
Number of students who experienced the level of understanding
%: Percentage of students who experience the level of understanding
Concept Label 1: Double-slit interference
Concept Label 2: Interference in thin films
Concept Label 3: Single slit diffraction
Concept Label 4: Diffraction Grating

TABLE 3 shows the level of understanding students have after taking the pretest with the level of student understanding. In question number 1 obtained as many as 0% of students Complete Understand (CU); 52% of students Partially Understand (PU); 42% of students Misconception (M); 3% of students Not Understand (NU); and 3% of students No Answer (NA). In question number 2 obtained as many as 0% of students CU; 42% of students PU; 45% of students M; 9% of students NU; and 3% of students NA. In question number 3, data obtained as much as 3% of students CU; 21% of students PU; 39% of students M; 18% of students NU; and 18% of students NA. In question number 4 obtained data as much as 0% of students CU; 6% of students PU; 30% of students M; 21% of students NU; and 42% of students NA. After learning activities using VMS media on light wave material have been completed, the posttest is completed. From the results of the posttest, calculations were then carried out to determine the level of students' understanding. The following levels of student understanding based on the posttest can be seen in TABLE 3.

TABLE 3. Students' Understanding Levels Based on Posttest

Level of Understanding	Characteristics of Student Answers	Concept Labels			
		1	2	3	4
		Σ %	Σ %	Σ %	Σ %
[4] Complete Understanding (CU)	Correctly answer all the questions on a question	21 (64)	2(6)	8(24)	4(12)
[3] Partial Understanding (PU)	Correctly answer some of the questions on a question	12(36)	25(76)	23(70)	16(48)
[2] Misconception (M)	Answer with all the questions on a question but the answer is not clear, or the answer is wrong	0(0)	6(18)	2(6)	13(39)
[1] Not Understanding (NU)	Answering all the questions on a question but the answers given are not appropriate (irrelevant) to the question	0(0)	0(0)	(0)	(0)
[0] No Answer (NA)	Does not provide answers to all questions on a question item	0(0)	0(0)	(0)	(0)

TABLE 4, the level of student understanding after taking the posttest with the level of student understanding. In question number 1 obtained as many as 64% of students Complete Understand (CU); 36% of students Partially Understand (PU); 0% of students Misconception (M); 0% of students Not Understanding (NU); and 0% of students No Answer (NA). In question number 2 obtained as many as 6% of students CU; 76% of students PU; 18% of students M; 0% of students NU; and 0% of students NA. In question number 3 obtained data as much as 24% of students CU; 70% of students PU; 6% of students M; 0% of students do NU; and 0% of students NA. In question number 4, data obtained as much as 12% of students CU; 48% of students PU; 39% of students M; 0% of students NU; and 0% of students NA. The results of the pretest and posttest were used to measure the use of VMS to increase the level of understanding in students by using the gain test. The following are the gain test results obtained from the pretest and posttest results as seen in TABLE 4.

TABLE 4. Gain Test Results

Test	Average	Normalized Gain (N-Gain)
Pretest	46.40	0.56
Posttest	77.65	

TABLE 4. the average value for the pretest is 46.40 and the average value for the posttest is 77.65. The results of statistical calculations using the gain test obtained an achievement of 0.56. The converting the value of the N-Gain calculation results in qualitative data analysis, it is obtained that the N-Gain data [16] is in the Medium criteria where 0.3 < N-gain 0.7. Based on the Likert scale interpretation, it can be synthesized that the light wave learning activities using VMS media increased students' understanding.

Several factors affect the increase in the level of understanding of the use of media in each student, among others: (1) VMS facilitates students in studying light waves; (2) VMS helps students to describe how the concept of light waves in students' minds; (3) The developed VMS shows microscopic and macroscopic visualization; (4) Microscopic visualization on VMS media helps students to build a more scientific view on the concepts of interference and light diffraction; and (5) learning with VMS influences students to be active in finding information and solving various problems so as to help students to improve their conceptual understanding in learning the concept of light waves. The use of computer simulations is more effective in improving students' abilities compared to the help of computer simulations (Siswoyo 2019; Çelik 2022). Other factors observed in learning occur due to differences in student concentration and interest when participating in learning. The effectiveness of VMS media in increasing students' level of understanding can also be caused by the role of VMS as a computer-based learning media that has been tested for its use in terms of validity, satisfaction, and effectiveness. VMS is a visual representation of physical phenomena that integrates text, images, and simulations to conduct experiments on light wave material, providing a concrete experience for students, student-centered learning activities and directing students to think high-level in problem solving. Thus, it can be concluded that the development of VMS media in light wave learning can increase students' level of understanding. The advantages of VMS media compared to research conducted by (Wibowo et al. 2017; Wibowo & Iswanto 2019), include: (1) the developed VMS successfully visualizes the concept of interference and light diffraction in real terms; (2) VMS helps students to build a more scientific view in studying light waves; (3) VMS is easy to use, and easy to install; (4) VMS provides satisfaction and benefits to students; and (5) Learning using VMS can increase students' level of understanding in learning the concepts of light interference and diffraction.

CONCLUSION

Physics learning media, namely Virtual Microscopic Simulation (VMS) has been successfully developed. The use of VMS media on light wave material can enhance the student's understanding level. Based on the study results, it can be concluded that the development of VMS on light wave material is valid to be used as a learning medium for students. The use of VMS media in light wave learning can increase the level of student understanding of light wave material. The limitations of VMS media in studying light waves is that the VMS is only limited to interference and light diffraction processes and does not include other characteristics of light waves such as polarization, dispersion, etc. The VMS application is too heavy so it requires a large storage memory, and the application can only be installed on several types and brands of computers.

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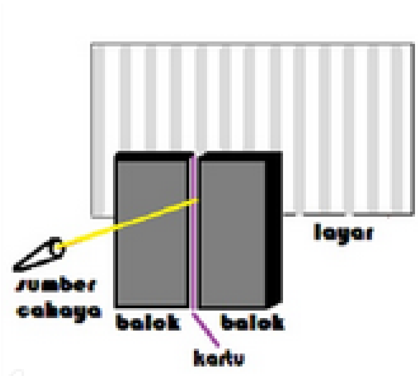
APPENDIX

Appendix 1. Test Level of Understanding

Test Level of Understanding	**Answer Key**
Budi did a simple experiment using two blocks where between the two blocks was inserted a narrow card with a width of 1 mm. Events are observed by providing a light source from the opposite direction to the screen. The results of taking pictures formed dark and light patterns as shown below.  From this experiment, it was found that the results of observations in the form of the formation of	A. The pattern of light and dark that forms on the screen occurs because the light rays travel towards the plate which is given two narrow slits. The rays coming out of the two slits send out circular waves that overlap outside the area of the two slits. This causes waves from one slit to interfere with waves from another slit which results in a fusion of the two waves to form a new wave. To prove this interference, we must cut the light by installing a screen so that on the screen there is an alternating pattern of light and dark. B. If the beam crush gap is changed, the bright and dark lines on the screen that are captured on the screen also change. If the distance between the slits is reduced, the distance between the bright and dark patterns formed from the light source to the screen will be smaller. This is because the relationship between the crushing gap distance and the interference pattern that is formed is directly proportional. C. If the wavelength used in the experiment is smaller than the width of the slits, then the light coming out of the two slits will not send out overlapping circular waves. If we cut

light and dark patterns were caught by the screen at 60 cm from the slit. The distance between the first bright line and the center bright line is 2 mm. A. Explain why a pattern of light and dark is formed on the screen? B. Explain what happens to the screen if the crushing gap in the beam is changed? C. Explain what happens to the interference pattern of light when the wavelength is much shorter than the distance between the two slits? D. d. Describe the conditions for the occurrence of constructive interference and destructive interference!	the propagation of the wave with the screen, then the screen will not form an interference pattern. D. Constructive interference is the result of a combination of two or more waves that reinforce each other so that bright lines are formed that appear on the screen. The condition for constructive interference is if the two light waves are in phase or the phase difference is zero. Meanwhile, destructive interference is the result of a combination of two waves that completely cancel each other out and appear dark areas on the screen. The condition for destructive interference occurs if the two light waves are in opposite phases or the phase difference is 180^o.