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Development of Learning Media For Vector Suvject Matter

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Abstract
This research focuses on the development of learning media to teach vector concepts to improve students' understanding of vector addition, vector projection, and dot product calculations. This research uses a Research and Development (R&D) approach, which involves media design using Corel Draw and CNC technology for acrylic material fabrication. Validation was conducted by subject matter experts and media specialists to ensure the accuracy and interactivity of the content, while field trials tested the effectiveness of the media with high school students. The results showed that the learning media achieved an accuracy level of 0.17% in the parallelogram method, 0.60% in component analysis, and 0.83% in dot product projection, indicating high precision in visualizing the magnitude and direction of vectors. Validation feedback rated the content, conceptual alignment, design, and interactivity as good to excellent, with an average score of 80-92%. Therefore, this learning tool is considered effective and useful in helping students overcome difficulties in mastering vector concepts.

Keywords: Learning Media; Vector Addition; Vector Projection; Dot Multiplication

INTRODUCTION

Learning media is anything that can be used, its function is to channel messages from the sender to the recipient so that it can stimulate the thoughts, feelings, attention and interests and attention of students in such a way that the learning process occurs(Faishol and Mashuri 2022; Romadiah, Dayurni, and Fajari 2022; Sirait, Harahap, and Handayani 2021). Good learning media must meet several requirements. Learning media can increase student motivation. The use of media has the aim of providing motivation to students. In addition, the media must also stimulate students to remember what has been learned in addition to providing new learning stimuli. Good media will also activate students in providing responses, feedback and also encourage students to practice correctly.

Vector is one of the concepts that is considered as a basic foundation for studying other topics in physics. So it is necessary to understand vectors to understand other topics in physics. In Indonesia, the topic of vectors begins to be studied by students in grade 10 of Senior High School. In the 2013 curriculum high school physics syllabus, the Basic Competence on vectors is to apply the principle of vector addition (with a geometric approach) and conduct experiments to determine the resultant vector(Alanazi 2020;

Dittrich 2015; Ravil Isyanov, Kamoliddin Rustamov, Nodira Rustamova 2020). The basic material studied is vector addition using the geometric method. Based on the researcher's direct observation, there is also enrichment material on the topic of vectors in high school, namely vector addition using the component analysis method and dot multiplication.

Based on observations, interviews, and questionnaires in order to conduct a needs analysis that has been conducted by researchers on the difficulties of students in understanding the subject of vectors in students from three different schools, the greatest difficulty experienced by students is the difficulty of drawing vector projections. Difficulty in adding vectors by 23%, difficulty in breaking down vector components by 42%, difficulty in drawing vector projections by 45%, difficulty in calculating the magnitude of vector components by 26%, and difficulty in determining the direction of vector components by 42%. Interviews with physics teachers were also conducted for needs analysis. The factors causing students to have difficulty in understanding the subject of vectors are the misconception of depicting the concept of vectors that are not based on the correct rules of vector addition, the misconception of understanding the definition of the concept that is not quite right, and the misconception in using vector formulas. The resource person also said that there is no special learning media for the subject of vectors, so it is very supportive if the development of learning media for the subject of vectors is carried out. The results of the needs analysis show the importance of research for the subject of vectors. Therefore, this study will examine the development of learning media for the subject of vectors(Hidayatulloh et al. 2021; Mutambara and Bansilal 2022).

Based on previous research that focused on junior high school students with basic mathematics material, especially social arithmetic, which is simpler than this research which targets high school students and discusses more complex physics concepts such as vectors, vector addition, and vector projection. In terms of the technology used, previous research developed digital media based on simple software, namely Microsoft PowerPoint, which is relatively easy to use by educators and students in class. In contrast, this research uses more sophisticated technology, namely acrylic physical devices designed and produced using Corel Draw design software and CNC machines. This difference shows a higher level of media sophistication in vector research(Anwar et al. 2020; Mutambara and Bansilal 2022).

In terms of interactivity approach, PowerPoint-based research focuses on interactive visual media through presentation displays to help students understand the material more interestingly. On the other hand, vector learning media is designed to provide a manipulative experience that allows students to interact directly with physical objects, helping them in visualization and deep understanding of abstract physics concepts. In terms of validation and effectiveness testing, both studies involve a validation process by experts and an effectiveness test on students. However, because the material handled in vector research is more complex, the validation process in this study requires a more detailed assessment of the suitability of the content, concept, design, and interactivity of the media developed(Jones 2020; Poluakan, Mondolang, and Mongan 2020).

Based on the gap analysis above, there is something new in this research, namely the technology used in this research, thus presenting innovative physical media that allows for the visualization of complex physics concepts(Kurniawan and Sumargono 2021).

The implications of this study provide important contributions to the understanding of more complex concepts at the high school level, such as vectors in physics. The implications of the development of this specially designed acrylic physical media are the importance of manipulative approaches and direct visualization to help students understand abstract concepts. This shows that carefully designed media can overcome students' learning difficulties and improve conceptual understanding in depth, so that it can be a reference for the development of similar media in other subjects.

This study highlights the importance of hands-on manipulation-based learning, which has been shown to be effective in helping students understand abstract concepts. By engaging students in the use of acrylic-based physical media and CNC technology, they not only gain theoretical understanding but also real-life experience of how vector concepts are applied in real life(Srikongchan, Kaewkuekool, and Mejaleurn 2021; Sugianto et al. 2022).

Physics materials, especially the concept of vectors, are often considered scary and boring by students. By presenting innovative and interactive learning media, this study aims to change this perception, making the learning process more interesting and enjoyable. This can motivate students to be more enthusiastic in learning and actively participate in class, thereby improving overall learning outcomes. This study has a high urgency to be carried out, because it contributes directly to improving the quality of physics learning, helping students understand difficult concepts, and providing innovative solutions that can be adopted in various educational institutions(Anggraeni and Maryanti 2021; Astuti, Wihardi, and Rochintaniawati 2020; Dita et al. 2021).

RESEARCH METHODS

Research Design

This study uses the research and development (R&D) method to develop and produce basic learning media for vector language. The R&D method was chosen because it is relevant to produce new products that are effective in the field of education(Zulfadewina, Adi Sucipto, Khairil Iba 2020).

The research was conducted at the Physics Education Laboratory of Jakarta State University for the development stage, while the trial of the learning media was conducted at Islamic High School Al-Azhar Kelapa Gading, Jakarta.

Research Target/Subject

Population The population in this study were all students of Islamic High School Al-Azhar Kelapa Gading Sample The technique used to determine the sample was purposive sampling (Kennedy-Shaffer, Qiu, and Hanage 2021; Yoon, Kim, and Lim 2012). The number of samples was 43 students consisting of students of class X Mathematics Natural Science 1 and X Mathematics Natural Science 2 of Islamic High School Al-Azhar Kelapa Gading.

Research Procedure

This research involves several main stages. First, the development stage, designing vector-based learning media using design software such as Corel Draw and producing components with CNC machines. Second, the validation stage, the learning media is validated by material experts and media experts to assess the suitability of the content, concept, design, and interactivity. Finally, the trial stage, conducting a trial of the use of learning media in the classroom to assess the effectiveness and accuracy of the learning media(Ganesha and Aithal 2022).

Instruments, and Data Collection Techniques

The instruments used in this study consisted of: Needs Analysis Questionnaire, Validation Questionnaire, Field Test Questionnaire. The data obtained were analyzed by calculating using a Likert scale. The instrument used in this study used a Likert scale with a score of 1-5 (Sugiyono, 2010: 134). 1 = not good / unclear 2 = less good / less clear 3 = good enough / clear enough 4 = good / clear 5 = very good / very clear.

Data analysis technique

Data were analyzed using a descriptive quantitative approach to determine the level of validity and effectiveness of learning media based on the results of trials and validation.

RESULTS AND DISCUSSION

The initial process in making learning media on the subject of vectors is to draw media components with the help of Corel Draw software. The next process is to print each component on acrylic using a CNC (Computer Numerical Control) cutting machine. After the printing process, improvements are made to the print results. The improvements made are by cleaning the remaining acrylic dregs on the scale and sanding each side of the component. The next process is coloring the scale. coloring the scale using marker ink. Several components are glued using Acrylic Glue. Several pieces of adhesive suction are also attached to several components.

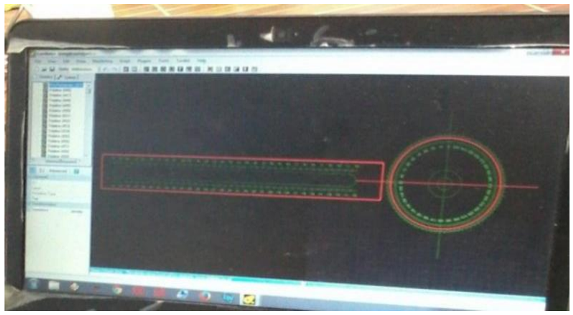

Figure 1. Creating Learning Media Design

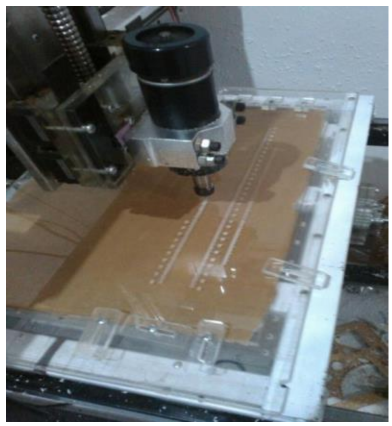

Figure 2. Making Learning Media Using CNC

The working principle of the vector learning media is based on the parallelogram method of vector addition. The first stage of use is to set the magnitude and direction of the two vectors to be added. Then set the magnitude of the two parallel sides of the vector so that they have the same magnitude as the parallel vector. The magnitude and direction of the resultant vector are immediately obtained. If a vector image of the resultant is needed, insert a marker into the four marker holes provided and then connect each point to the coordinate center using one of the vector learning media rod components. This learning media is equipped with positive and negative scales that allow users to add vectors in various quadrants in a two-dimensional plane. If the vectors to be added are more than two vectors, then add the two vectors first, then the resultant is added again with the next vector.

The learning media of the subject of vectors is also used to find the projection of a vector onto another vector or the projection of a vector onto the Cartesian coordinate axes. The projection of a vector onto another vector can be used to calculate the dot product value between the two vectors. The projection of a vector onto the Cartesian coordinate axes is used for the addition of vectors using the component analysis method.

The trial of the vector learning media was carried out by comparing the measurement results and calculation results based on the theory (Equation 13) to determine the level of accuracy of this learning media. The following is a trial of the vector learning media: The parallelogram method is one technique for finding the magnitude and direction of the resultant of two vectors. The first step is to determine the two vectors to be added. After that, the learning media is placed on the board and glued using adhesive rubber. Furthermore, the angle between the two vectors is set by rotating the V and H rods and the arc. The magnitude of the vector on the H Rod is set by sliding the Lower Slide until the scale shows the magnitude of vector 1. The same thing is done on the V rod to determine the magnitude of vector 2, then locked by turning the lock clockwise. After that, the V1 Rod is shifted until the scale on the Upper Slide of the H Rod matches the Lower Scale of the V Rod, then locked. The rotating rod is rotated until the scale on the Upper Slide of the V Rod matches the scale of the Lower Slide of the H Rod. The scale shown on the Rotating Rod Slide is the magnitude of the resultant of the two vectors, while the direction of the resultant vector is indicated by the scale on the arc. For visualization, the marker is inserted into the slide hole and the center, the media is removed from the whiteboard, then the vector 1, vector 2, and resultant points are connected to the center point. The resulting image shows a parallelogram visualization representing the vectors and their resultants.

The data obtained from the vector addition method parallelogram using this learning media is the magnitude and direction of the resultant of two vectors. The data from the trial of the learning media on the subject of vectors in the material on the vector addition method parallelogram are as follows:

Table 1. Trial Data for Vector Addition Using the Parallelogram Method

Vector 1 (N)	Vector 2(N)	The angle between vectors 1 and 2 (°)	Resultant	Result	Direction Measurement Results
			Theory Result (N)	Measurement Result (N)	Resultant Against Vector 1 (°)
15	25	90	29.2	29.1	60
20	25	90	32.0	32	51
25	25	90	35.4	35.4	45
15	25	60	35.0	35.1	40
20	25	80	34.6	34.5	46
25	25	80	38.3	38.3	40
15	25	70	33.3	33.2	45
20	25	70	37.0	37	40
20	25	110	26.1	26.1	65
20	25	132	18.9	18.8	81

Based on the data above, the learning media for the subject of vectors has an accuracy level of 0.17%. This shows that the scale of the vector learning media is very accurate for determining the magnitude and direction of the resultant vector based on the geometric method.

Vector Addition Using Component Analysis Method. In addition to the parallelogram method, vector addition using vector learning media can also be done using the vector component analysis method. The method of vector addition using vector learning media based on the analysis method is as follows: To determine the components of a vector using the parallelogram method, first place the learning media on the board and press all the adhesives so that the media remains stable. Rotate the arc until the 0° position is parallel to the positive X-axis in Cartesian coordinates. Select the vector to be added and describe its components by paying attention to the position of the vector in a particular quadrant. Then, direct the V rod and H rod to show the Y axis and X axis in that quadrant. Adjust the rotating rod slide to show the magnitude of the vector, then lock its position. Move Rod V1 perpendicular to rod H by adjusting the vertical line on the top slide of rod H to align with the number on the bottom slide of rod H, then lock it. Next, move Rod H1 perpendicular to rod V by aligning the vertical line on the top slide of rod V with the number on the bottom slide of rod V, then lock it again. The number on the bottom slide pointer of the H bar indicates the magnitude and direction of the x component, while the number on the bottom slide pointer of the V bar indicates the magnitude and direction of the y component of the vector. Mark each vector and its components by inserting colored markers in all the holes as markers, then record the data. Repeat these steps for each other vector. After all the vectors have been decomposed into their components, add up all the components on the X and Y axes. The result of this addition is the components of the resultant vector on the X and Y axes. Finally, calculate the magnitude and direction of the resultant vector based on these components, so that the final magnitude and direction of the combination of the existing vectors are obtained.

The data from the trial of learning media on the subject of vectors in the vector addition material using the component ana
lysis method are as follows:

Table 2. Trial Data of Vector Addition Analysis Method

V_1 (N)	θ_1 (°) *	V_2(N)	θ_2 (°) *	R_h (N)	R_u (N)	θ_{Ru} (°) *
15	25	25	115	29.2	29.0	60
20	30	25	120	32.0	32.1	51
25	60	25	150	35.4	35.6	45
15	70	25	130	35.0	34.9	40
20	80	25	160	34.6	34.9	46
25	90	25	170	38.3	38.0	40
15	100	25	170	33.3	33.1	45
20	110	25	180	37.0	37.2	40
20	20	25	130	26.1	26.2	65
20	10	25	142	18.9	18.7	81

Description:
V 1 = First vector
Rh = Result based on theory
θ1 = Angle of first vector
Ru = Resultant measurement result
V2 = Second vector
θRu = Direction of resultant

Based on the data above, the learning media for the subject of vectors has an accuracy level of 0.60%. This shows that the scale of the vector learning media is very accurate in determining the magnitude and direction of the resultant vector based on the analysis method.

Validation by material experts was conducted in the Physics Department of Faculty of mathematics natural science, Jakarta State University. Two material experts were involved in this study. The validation instrument by material experts consisted of two indicators, namely (1) suitability of content consisting of four questions, and (2) suitability of concept consisting of five questions. The assessment was given in the material expert validation sheet. The data obtained from the material expert validation are as follows:

Table 3. Data from Material Expert Validation Results

No	Indicator	Average Score (%)	Assessment
1	Contentn Suitability	78	Good
2	Concept Suitability	82	Very Good
Average media result		80	Good

From the results of the validation by material experts, the average for all indicators was 80%. Based on the Likert scale, it was assessed that the quality of the learning media for the main topic of vectors in terms of the suitability of the content and the suitability of the concept was considered good.

Validation by learning media experts was conducted in the physics department of FMIPA, Jakarta State University. There were three learning media experts involved in this study. The media expert validation instrument consisted of two indicators, namely (1) design suitability consisting of eleven questions, and (2) interactive consisting of two questions. The assessment was given in the physics learning media expert validation sheet. The data obtained from the validation of the learning media expert are as follows.

Table 4. Media Expert Validation Results Data

No	Indicator	Average Score (%)	Assessment
1	Design conformity	84	Very Good
2	interactive	83	Very Good
Average media results		83	Very Good

From the results of the validation of learning media experts, the average for all indicators was 83%. Based on the Likert scale, it was assessed that the quality of the learning media for the subject of vectors in terms of design suitability and interactivity was considered very good.

After being validated by media experts, material experts, and high school physics teachers, the learning media was also tested by students. The trial questionnaire consisted of two indicators, namely (1) design suitability containing 12 questions and (2) interactivity containing two questions. The assessment was given on the student trial questionnaire. The data obtained from the student trial questionnaire are as follows:

Table 5. High School Student Trial Result Data

No	Indicator	Average Score	Assessment
1	design conformity	91	Very Good
2	interactive	92	Very Good
Average media results		92	Very Good

Based on the student trial, the average overall aspect was 92%. Based on the Likert scale, the assessment was that the quality of the learning media was very good. Needs analysis shows that students need learning media that can help them overcome their difficulties in the subject of vectors. The difficulties experienced by students include difficulty in calculating the magnitude and direction of the resultant vector, describing vector components, drawing vector projections, calculating the magnitude of vector components, and the unavailability of learning media for the subject of vectors in schools. Therefore, the researcher created learning media for the subject of vectors.

The vector learning media is made of 8 mm and 4 mm thick Acrylic. Each component of the learning media is made separately for easy carrying. Each component is drawn using Corel Draw, then cut and carved to scale using a CNC cutting machine. Several component parts are put together using acrylic glue. The assembly of the vector learning media is carried out after all components are formed.

The next process is the trial of the learning media. The trial was conducted to determine the level of accuracy of the learning media. The trial of the learning media on the subject of vectors on the material of vector addition using the parallelogram method, component analysis method, and dot multiplication. The level of accuracy of the learning media when tested on the material of vector addition using the parallelogram method was 0.17%. This shows that this learning media is very accurate in finding the magnitude and direction of the resultant vector. From this trial, students' difficulties in calculating the magnitude and direction of the resultant vector and the difficulty in drawing vectors can be overcome.

The level of accuracy of the learning media when tested on the vector addition material using the component analysis method is 0.60%. This shows that this learning media is very accurate in finding the magnitude of the vector components on the Cartesian coordinate axes. From this trial, students' difficulties in calculating the magnitude of vector components and difficulties in drawing vector components can be overcome.

The level of accuracy of the learning media when tested on the dot multiplication material is 0.83%. This shows that this learning media is very accurate in finding the magnitude of the projection of a vector on another vector which has an impact on finding the result of the dot multiplication between the two vectors.

The level of accuracy during the vector addition trial of the analysis method is greater than during the vector addition trial of the parallelogram method. This is caused by the parallax error factor. The average value of the learning media accuracy level is 0.53%. From this average, it can be concluded that the learning media for the subject of vectors is very accurate and is a solution to students' difficulties in the subject of vectors.

The validation process was carried out by material experts, media experts, and high school physics teachers. The results of the material validation obtained an average of 80%. These data indicate that the quality of the vector subject learning media from this suitability indicator and the suitability of the concept is considered good. The results of the media validation obtained an average of 83%. These data indicate that the quality of the vector subject learning media from the design and interactivity suitability indicators is considered very good. The results of the teacher validation obtained an average of 90%. These data indicate that the quality of the vector subject learning media from the content suitability, concept suitability, design suitability, and interactivity indicators is considered very good. The trial was also carried out by students and obtained an average of 92%. This shows that this learning media is very good from the interactivity and design indicators.

From all the validation results, it can be said that the vector learning media is suitable for use as a learning media based on the indicators of content suitability, concept suitability, design suitability, and interactivity.

Based on previous research that has been conducted, there is a gap based on the results of research findings, where previous research focused on the development of IT-based learning media, emphasizing how technology can improve the learning experience through various media such as the internet, intranet, and mobile learning. This study highlights the need for IT integration in the educational environment to increase engagement and effective learning. While in this study, it examines how the use of puzzle-based learning media to improve learning outcomes in elementary science classes through the Classroom Action Research (CAR) model, and this study focuses on increasing student engagement and cognitive interaction with scientific concepts(Puspita Sari and Setiawan 2018; Yani et al. 2020).

Although both studies discuss the use of media to enhance learning, previous studies are more general in the use of IT-based media in various subjects, while this study is more specific in the use of puzzle media for elementary science education. There is a gap in exploring a comprehensive approach that combines IT and hands-on learning tools for holistic engagement.

The novelty of this study lies in the application of a puzzle-based and hands-on approach to elementary science education, demonstrating engagement and cognitive learning outcomes through real classroom data. This differs from previous studies, which have taken a broader view of IT-based learning tools without a specific focus on a single tactile media approach. Combining insights from both studies suggests a novel approach that integrates digital media and hands-on, providing a multifaceted engagement strategy for learners.

The implications of this study from an educational practice perspective are that a varied media approach, whether digital (as proposed by Muhson) or physical (as demonstrated by Oktaviani), significantly increases engagement and learning outcomes. Educators should adapt media based on subject requirements, combining digital and physical media where necessary to create flexible learning environments. Furthermore, from a policy and development perspective, policymakers can leverage these insights to develop curriculum standards that emphasize the use of adaptive and diverse media, ensuring that learning approaches meet the diverse needs and cognitive abilities of students.

The limitation of this study lies in the application of puzzle-based media limited to one subject (science) and a certain grade level. The findings cannot be generalized to other subjects or levels of education. In addition, external factors such as socio-economic influences, parental support, and access to resources are not controlled, which can affect learning outcomes.

CONCLUSION

This study concludes that vector-based learning media from acrylic material with the help of Corel Draw and CNC machines are very effective and accurate in supporting students' understanding of vector material. The trial showed a high level of accuracy in three measurement methods: the parallelogram method (0.17%), the component analysis method (0.60%), and the dot product (0.83%). Validation by material experts, media experts, high school physics teachers, and student trials showed good to very good assessments in terms of content, concept, design, and interactivity, with an average score of 80-92%. This media has proven to be feasible and helps students overcome difficulties in understanding vector concepts.

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