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Improving Graphical and Numerical Representational Competence Coherence with Laboratory Investigation and Computer to Solve Problem-Solving of Geometry Optical Materials

Wawan Bunawan[1*], Satria Mihardi[1], Pardomuan Sitompul[2], Irham Ramadhani[1]

[1] Department of Physics, Faculty of Mathematics and Sciences, Universitas Negeri Medan, Medan, Indonesia.
[2] Department of Mathematics, Faculty of Mathematics and Sciences, Universitas Negeri Medan, Medan, Indonesia.

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Corresponding Author:
Wawan Bunawan
wawanbunawan@unimed.ac.id

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Abstract: Learning physics through the investigation of phenomena using practicum equipment in the laboratory is the real core of learning physics. The basic competence of prospective science teachers towards understanding concepts through investigating phenomena is well developed. The achievement of other, more abstract concept representation competencies such as numerical, graphical, and mathematical representations requires new methods or ways in the learning process. The development of computer technology as part of further investigation of learning in the laboratory needs to be developed to facilitate learning. The purpose of this research is to investigate how to improve competence in understanding concepts based on verbal representations (Verb Rep) in the form of investigations of phenomena, to achieve multiple representations (MR) (Formal Representation, Numerical Representation, Graphical Representation, Pictorial Representation) with computer-based learning. The results showed that the conventional group (N=30; M=72.87; SD = 7.03; SE = 1.28) had a lower average score on the test results than the experimental group (N = 30; M = 83.27; SD = 4.93; SE = 0.89). Independent mean statistical tests showed significant differences (t (30) = -6.63; p <0.001; r = 0.78) between groups learning to use one representation (conventional) and those using MR to solve problem-solving cases of lens content and curved mirrors, with the category of effect size (r)0.78 exceeding 0.50 (large effect).

Keywords: Geometrical optic; Graphical representation; Laboratory investigation; Numerical representation; Problem-solving

Introduction

The word representation in the learning context is intended as an entity that represents an object. The objects referred to in this article are concepts in geometric optical materials such as the subject matter of lenses and curved mirrors. The concept represented and the form of representation must have an appropriate and meaningful connection physically and theoretically in the scientific field of physics education (Scheid et al., 2019). The existence of physics concepts of a material generally has more than one representation, including Verbal Representation (VR), Mathematical Formal Representation (FR), Pictorial Representation (PR), Graphical Representation (GR), Numerical Representation (NR).

Competence in solving problem-solving (PS) cases in geometric optical material require a deep and scientifically correct understanding of physics to be able to connect the MR of each of its components (Gregório et al., 2020; Lertyosbordin et al., 2021; Simon & Swerdlik, 2022). Errors in understanding the connections between representations result in errors in providing solutions from the actual concept (Klein et al., 2017). Learning

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efforts can be carried out by teachers to be able to provide assistance in conventional learning processes and use computers to achieve more optimal learning goals (Young et al., 2019). Coherence between learning based on laboratory inquiry followed by direct learning in the terminology of the problem-solving learning process is known as the conventional learning process (Lembang et al., 2021; Malik et al., 2019; Nurbaya et al., 2015; Tang et al., 2022). The result of the learning process is student competence in solving problem-solving questions. The reality related to PS competence still needs improvement (Burkholder et al., 2020).

The urgency of the research is to find a new learning process strategy that can provide efforts to improve the quality of student PS through the synergy of the learning process involving separate MR and involving computer-assisted MR for simultaneous graphical and numerical representations; Provides an overview of the role of using conventional and computer-based approaches to teach the concept of curved lenses and mirrors with MR approaches and precision connections between sub-representations; and Provide an empirical comparison of the success of the MR approach to PS competence between two groups given different learning. Benefits the study provides an overview of the implementation of the use of separate MR and the use of integrated MR with the help of a computer to achieve an increase in PS quality based on qualitative and quantitative analysis through relevant statistical tests.

Method

The research sample uses two groups. The conventional study group consisted of 30 students with a manual MR learning process. The other group consisted of 30 students as the experimental group with manual MR learning and using program computing media. The total sample technique was chosen because the population for the optical geometry course is only two classes.

The implementation of the research was carried out in several stages: Conducting investigations using inquiry equipment in the laboratory. This stage aims to identify the process of image formation produced by the optical object of the lens and curved mirror. The next goal is to find the relationship between the position of the object and the image and the characteristics of the resulting image. Data analysis and the process of graphing the relationship between object distance and image. This learning stage is carried out in groups; Conduct a literature study to analyze the relationship between concepts by involving relevant MR. The literature study was carried out in groups and independently; Conduct class discussions to analyze issues related to problem-solving cases and display the results of the investigations; The last stage of the conventional group carried out the updating of the concept involving MR with the guidance of the university textbooks, and the experimental group carried out MR studies and analysis with the help of a computer in the form of numerical modeling and synthetic data graphical analysis. This research was conducted using a quasi-experimental design with a research design model as shown in Table 1.

Table 1. Research Design Conducted for MR Testing

Class	Treatment	Learning Outcomes
Conventional	Inquiry lab, problem-solving, literature study	O1
Experiment	Inquiry lab, problem-solving, literature study, computer data analysis	O2

The test score data from the experimental class and the conventional class for each participant totaled 15 students, thus obtaining 30 test score data. The next step is to input data into the Data menu in SPSS to do data coding on view variables and data views. The next step is to select the analysis menu and then select compare mean. The t-independent statistical test method for two different groups was chosen according to the research objectives. Interpretation of the results of the execution of the SPSS program is carried out by researchers according to the needs and objectives that have been set.

The instruments used to obtain MR problem-solving case test data for lenses and curved mirrors must meet the qualifications of the validity and reliability tests. The characteristics of the validity and reliability of this test were carried out by analyzing data using SPSS on the Analysis menu and selecting Scale according to the empirical data from the two groups of participants.

Problem-Solving Test Instrument

PS competency as one of the benchmarks for measuring the success of the learning process using the MR approach for computer-assisted experimental classes and conventional classes using the conventional MR approach is measured using multiple-choice tests accompanied by written reasons. Standardized test terms have been used to provide a scientific benchmark for the validity and reliability of the test. The items in the test constructor have met the requirements for the level of difficulty and discriminating power by the classical test theory.

PS test questions consist of 5 MR with each representation represented by 5 items, thus the number of PS test questions totals 25 items. Internal test reliability is calculated using the Cronbach alpha formula with an index of 0.88 and content validity is based on the assessment of 2 test validators. Calculation of the validation index using Cohen Kappa with an index of 0.36 p = 0.01 < 0.05 so that it can be concluded based on the test validator that has been developed according to the needs of what the test is used for. The range of item difficulty levels was between 0.32 and 0.78 and the discriminating power index for each item was greater than 0.23.

Result and Discussion

Lens and mirror material in the learning process is delivered based on the observation process in the laboratory. The inquiry process aims to investigate how the process of forming the image of an object is produced by the optical object. The process of refraction of light by a lens with several main rays will produce images with different characteristics based on the position of the object from the lens and the type of lens. The same principle applies to curved mirrors, but the image formation process is based on light reflection, not light refraction. Figure 1 shows the process of image formation by a positive lens as one of the image representations (pictorial).

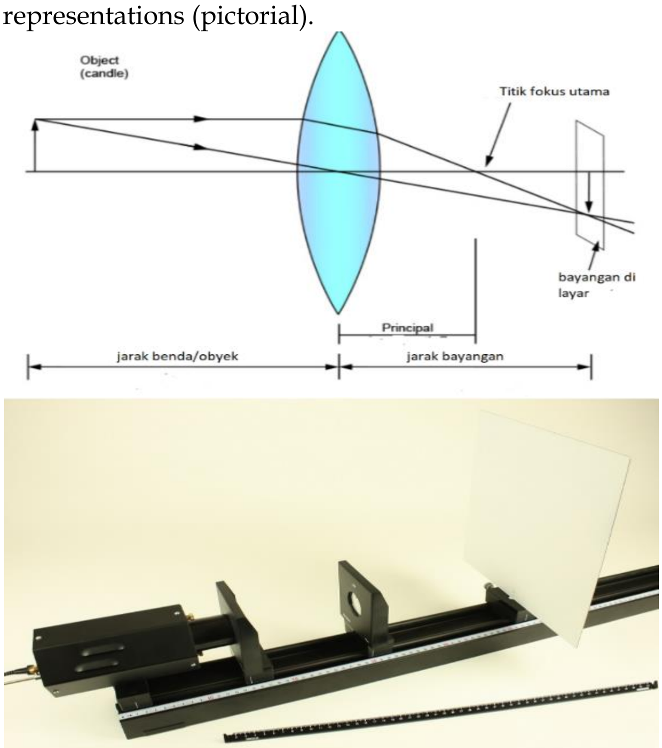

Figure 1. Image representation of the process of image formation by the lens

Lenses and curved mirrors share the same kind of conceptual representation. These two types of optical objects display their self-concept in 5 representations (verbal, pictorial, graphical, numerical, and formal) as shown in Figure 2. The connection between representations in pairs or all simultaneously shows the complexity of the concept of curved mirrors and lenses.

The learning outcomes of curved mirrors and lenses for the two learning groups in the experimental class and conventional class, especially in problem-solving competence (PS) are shown in Table 2. Learning outcomes are obtained from multiple-choice tests but are equipped with written answer sheets as proof that the answers given are not only guessed but based on accurate calculations and full analysis.

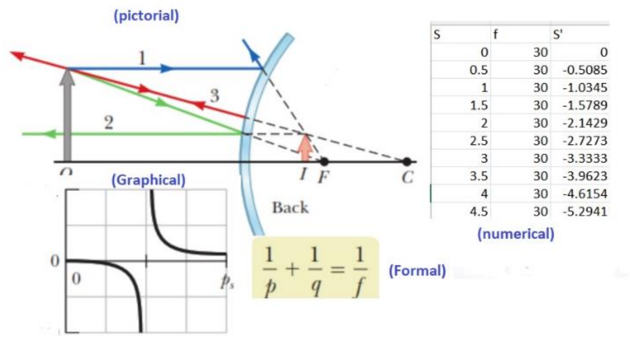

Figure 2. Multi-representation of mirrors and lenses

The problem-solving ability of the experimental class has a higher average score than the conventional class (83.27 > 72.87) with a small standard deviation, a maximum score of 90, and a minimum score of 75. Descriptive statistics for samples can be seen in Table 3. The results of testing the average PS score between the experimental and conventional classes can be seen in Table 4. The average PS score of the experimental class differed significantly with a probability of <0.001 with the standard significance test at alpha 0.05, thus it can be interpreted that learning with computer-assisted MR can improve understanding and analysis which is superior to learning that applies MR manually or conventionally.

Table 2. Comparison of the PS Scores of the Experimental and Conventional Groups

Group Statistics				
	Group	N	Means; SD	SEM
Problem-Solving	Conventional	30	72.87; 7.03	1.28
	Experiment	30	83.27; 4.92	0.89

The assumption that the variance scores of the two classes were either considered significant or not significantly different still resulted in a higher difference in the average test score of the experimental class (t = -6.63; df = 58; p <0.001).

Testing the impact of the MR learning process using computer assistance compared to only manual MR can be seen from the effect size value with the formula (1) (Field, 2009). The substitution t = -6.63 and df = 58 obtained r = 0.78 > 0.50. This has a big impact on achieving PS competence in the experimental class compared to the conventional class. The results of this study have a large impact as reported by the implementation of MR in physics learning widely (Munfaridah et al., 2021).

Table 3. Descriptive Statistics

Descriptive Statistics		
	Experimental class	Conventional Class
Means	83.27	72.87
Standard Error	0.89	1.28
Median	80	70
Mode	80	70
Standard Deviations	4.93	7.04
Sample Variance	2.43	4.95
kurtosis	-1.79	0.25
Skewness	0.03	1.06
Range	15	23
Minimum	75	65
Maximum	90	88
sum	2,498	2,186
Count	30	30
Confidence Level (95.0%)	1.84	2.63

$$r = \sqrt{\frac{t^2}{t^2+df}} \quad (1)$$

Question number 7 from one of the PS test numbers, this question is one of the complicated questions that combines graphical and formal representation competencies. PS statements or questions related to combined MR can be seen in Figure 3. The main difficulty is how test takers can calculate the focal length of a curved mirror. A cursory analysis of the lack of data because the cases in question are outside the graph in the question.

Table 4. Test the Average PS Scores of Experimental and Conventional Classes

		Levene's Test for Equality of Variances				
		F	Sig	t	df	Sig(2-tailed)
Problem-solving	Equal variances assumed	1.80	0.19	-6.63	58	< 0.001
	Equal variances not assumed			-6.63	51.92	< 0.001

The analytical skills of asymptotic graphical representations and formal representations can be combined to determine the focal size of a mirror. After the mirror focus value can be calculated correctly, the next step is to calculate the image produced by the mirror using the data from the problem. This work step must be proficient in learning to apply conventional MR principles.

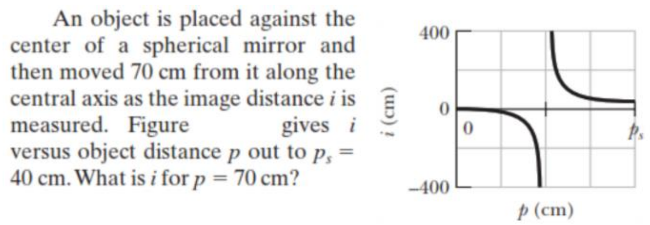

Figure 3. PS test item number 7 MR graphical (Halliday et al., 2014)

Students who experience the MR learning process with the help of a computer can perform a faster and more in-depth analysis (Permadi, 2018; Permadi & Setyaningsih, 2018). Based on his learning experience, the graph in question 7 can be reproduced using the Excel program with synthetic data that can be made based on the curved mirror formula. The curved mirror formula relates the characteristic magnitude of the object distance, the image distance produced by the mirror, and the mirror focus. Hundreds of synthesized data were used during the graphical reproduction of problem number 7 and can be seen in the graphical representation in Figure 4. The solution to problem number 7 can be obtained from data reduction which can be shown in Figure 5. Figure 5 is a numerical representation of data processing based on the work steps of the Excel program. How to work in Excel will be more compact if it is formed or packaged in the form of worksheets (Doyan et al., 2021).

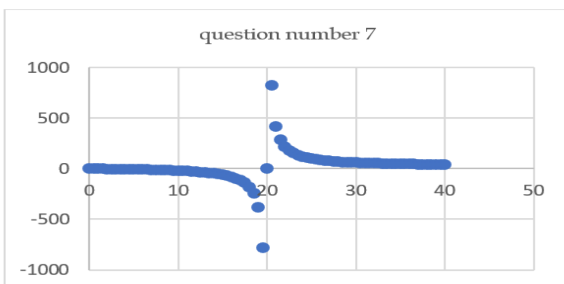

Figure 4. Graphical representation of image distance vs object distance of a curved mirror

PS ability can be increased if there is the ability to find solutions in many ways (Hobri et al., 2020; Khalid et al., 2020). As an illustration, question number 7 is a PS question with a difficulty level (index) of 0.35 (35% of the test takers who answered correctly). Participants in this test have the basic idea of determining in advance the focal length of the question data on the chart. Substitution of data into formulas (2).

S	f	S'
0	20	0
0.5	20	-0.5128
1	20	-1.0526
1.5	20	-1.6216
2	20	-2.2222
2.5	20	-2.8571
3	20	-3.5294
3.5	20	-4.2424
4	20	-5
4.5	20	-5.8065
5	20	-6.6667
5.5	20	-7.5862
67	20	28.5106
67.5	20	28.4211
68	20	28.3333
68.5	20	28.2474
69	20	28.1633
69.5	20	28.0808
70	20	28
70.5	20	27.9208

Figure 5. Numerical representation to determine the answer to PS question number 7

$$\frac{1}{20}+\frac{1}{\sim}=\frac{1}{f}\ \mathit{yield}\ f = 20 \quad (2)$$

The next PS procedure is to substitute the problem data into the equation to determine the image distance,

$$\frac{1}{70}+\frac{1}{i}=\frac{1}{20}\ \mathit{yield\ image\ distance}\ (i) = 28 \quad (3)$$

Two representations are involved in the solution process which is an integral part of problem-solving (Leak et al., 2017). Problem-solving ability can be improved by using coherence between multiple representations of relevant concepts. During the learning process, the implementation of computer-assisted MR numerical solutions can be done with Excel to produce the same solution data as shown in Figure 5. Likewise, the illustration of the problem using graphical representation can be reproduced in Figure 4.

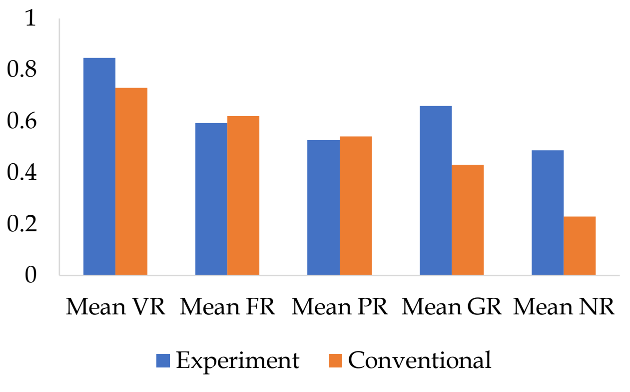

Figure 6. Comparison of the average achievement of the MR component

Synchronizing the steps for solving PS questions, whether done by conventional MR or by computer program-assisted MR, must have perfect accuracy (100%). If it is out of sync, it is worth re-checking the two MR settlement modes used (Krisnaningsih et al., 2021; Lakshmi & Krishnammal, 2022; Li et al., 2019; Suharsono & Zainuddin, 2021; Sunarti, 2022). The advantages of the PS solution process with computer-assisted MR can be replicated with perfect correctness and time efficiency for similar problems. Lens material and curved mirrors have at least 5 MR representations or multiple representations, including Verbal Representation (VR); Mathematical Formal Representation (FR); Pictorial Representation (PR); Graphical Representation (GR); Numerical Representation (NR). All of these representations are interconnected to form a single unit in building an understanding of the characteristics of the concept of a curved lens and mirror. MR in this lecture material is important in understanding facts, implementation, and understanding in providing scientific arguments related to problem-solving cases. Coherence between representations in building conceptual understanding is not possible to rely solely on one representation (Scheid et al., 2019). The achievement index of each representation component can be seen in Figure 6. The experimental class is superior in achieving VR, NR, and GR representations (Fithrathy & Ariswan, 2019; Nurrahmawati et al., 2021; Rahmawati et al., 2017; Zhang et al., 2022). Insight into students who are experienced in making graphs and performing numerical calculations with Excel can predict data outside of graphs, the impact will have even better VR (Theasy et al., 2018).

Conclusion

Physics learning for lenses and curved mirrors that are rich in representation or MR should start with a learning process in the laboratory to investigate the relationship between objects and the images produced by these two optical objects. The next continuation of the learning process is the exploration of the results of investigations and literature studies to provide an analysis of phenomena. Empirical analysis of data involving plotting of observational data to produce graphical representations and images between object positions and the resulting shadows. The next step is to carry out an in-depth study of the various PS cases that are relevant to examine the relationship between various representations. The last step is to carry out in-depth analysis and exploration by synthetic data using computer assistance to see various theoretical and empirical coherences. This learning strategy step has a major impact on problem-solving abilities that can be maximized.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: Bunawan, W.; data collection: Sitompul, P.; analysis and interpretation of results: Ramadhani, I.; draft manuscript preparation: Bunawan, W., Mihardi, S. All authors reviewed the results and approved the final version of the manuscript.

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Conflicts of Interest

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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