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Improvising the Design of Optical Geometric Experiment Apparatus for Pre-University Physic Course

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Abstract

Several difficulties have arisen for pre-university physics students using the retort stand as a laboratory apparatus for optical geometric experiments. The school staffs introduced the G-Optic Slider in 2020 to improve students' understanding and address the need for more conventional setups in optical geometric studies. The G-Optic Slider uses a fixed pin mechanism, a ruler, and recycled plastic pipettes to handle visualization and pin location. The present analysis highlights the G-Optic Slider's design limitations and emphasizes further improvement. The research goals include finding flaws, rebuilding the apparatus, and building a prototype, emphasizing convex lens experiments for Form Six Physics Courses. The research incorporates sustainability components via eco-friendly materials and fosters cooperation across educational institutions to improve student involvement, comprehension, and overall grades. Three concepts of improved G-Optic Slider were studied, and the selected proposal was designed using SolidWorks software. The suggested design has a pinion, rack mechanism, and PLA as the material. The drawing was then transferred to CuraMaker software for the 3D printing manufacturing process. Additional recommendations include a movable lens holder, simple mechanism, durable materials like polypropylene, and practical 3D printing for low-cost manufacturing. Finally, this project effectively overcomes shortcomings in the current Optical Geometric Experiment Apparatus and provides a better design that improves physics students' pre-university learning experience. The study emphasizes the continuous need for research to improve and optimize instrument designs, laying the foundation for future advancements.

1. Introduction

Geometrical optics is a captivating branch of optics that investigates the behaviour of light particles and their interactions with different optical elements [1]. In the landscape of pre-university physics education in Malaysia, the study of geometrical optics is integral, examining the behavior of light as it interacts with optical systems. A critical experiment involves determining the focal length of a convex lens using a traditional setup with a retort stand. The focal length of a convex lens is a fundamental property that determines its ability to converge light rays. It is an important parameter in understanding how the lens forms images and affects the magnification of objects [2]. Non-parallax method is one of the methods to find the focal length of convex lens. It already stated by Majlis Peperiksaan Malaysia, that all pre university physics students must use this method in findings the focal length of convex lens experiment. The non-parallax method is a technique used to determine the focal length of a convex lens by eliminating parallax [3]. One of the main problems faced by the students during the experiment is they have difficulty to understand what are the accurate results they are supposed to look for because they cannot easily recognize the perfect object visualization at the experiment apparatus. In response to this problem, Ms. Choo and Mr. Ghani from SMK Dato' Bentara Luar, Batu Pahat, introduced the G-Optic Slider in 2020. This innovative idea was very helpful in the learning sessions for students understanding of the topic.

Despite its advantages, the current G-Optic Slider design presents limitations impacting practical demonstrations and hindering students' full grasp of the optical principles. Challenges in adjusting measuring tools, reading accuracy, and material selection affect overall performance. Material choices may introduce errors and instability, necessitating a more tailored design before widespread adoption in Malaysian schools. To handle these concerns, a project is underway to enhance the G-Optic Slider by improving its moving mechanism, measuring tools, and materials. The objectives include identifying weaknesses in the existing apparatus, redesigning it for enhanced performance, and building a prototype of the improved Optical Geometric Experiment Apparatus. Students need to conduct this crucial experiment to expand their understanding of optical geometry. Moreover, a grasp of geometrical optics is indispensable for the development and enhancement of optical systems like telescopes, microscopes, and cameras [4].

2. Methodology

This section describes the material and methods that are proposed to improve the design of optical geometric experiment apparatus.

2.1 Design process

The methodology for the project, depicted in Fig 1, began with a focused identification of the problem statement, necessitating a site visit to SMK Dato' Bentara Luar, Batu Pahat, in collaboration with UTHM. Interviews with the pre-university physics teacher and laboratory assistant provided valuable insights into the challenges associated with the existing apparatus. These sessions were carefully crafted to gather comprehensive feedback, forming the foundation for the subsequent product requirements.

Following the problem identification phase, a thorough literature review was conducted, analyzing data sources from previous studies to support the research. This review encompassed theories, models, tools, and methods, offering a robust understanding of the project's context. Idea generation played a crucial role in designing an apparatus for the geometrical optics experiment, with sketches aiding in visualizing solutions to identified problems. The chosen design underwent a meticulous process involving material selection and conceptual analysis, leading to the development of a feasible design ready for the following stages.

The project's final phases involved using CAD software for parametric design, identifying product specifications, and generating detailed engineering drawings. The selected design was then released for manufacturing, culminating in producing a prototype. This prototype underwent rigorous testing to validate its effectiveness in addressing student challenges while identifying and rectifying potential design issues. Overall, the methodology provided a systematic approach, combining on-site research, literature review, and iterative design processes to develop a solution tailored to end-users needs.

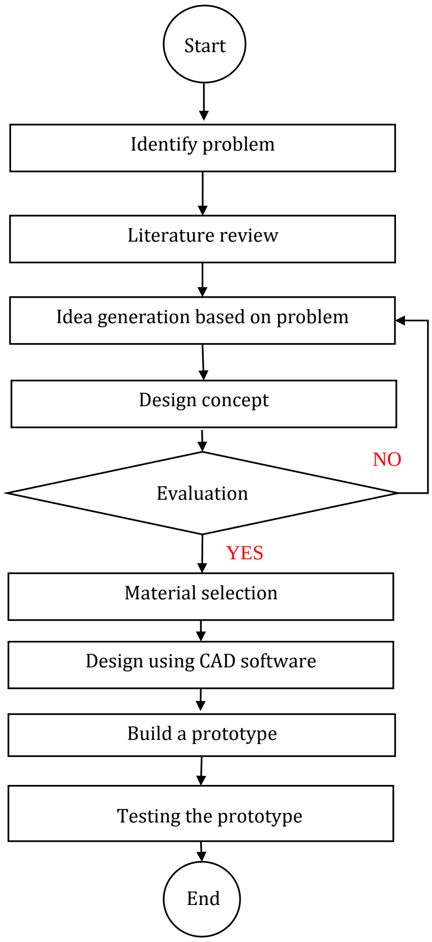


Fig 1 Flow chart for the methodology process

2.2 Concept Sketching

Concept sketching is a crucial step in preparing the initial concepts for product development. **Fig 2** presents several concept sketches that were generated during the ideation phase,

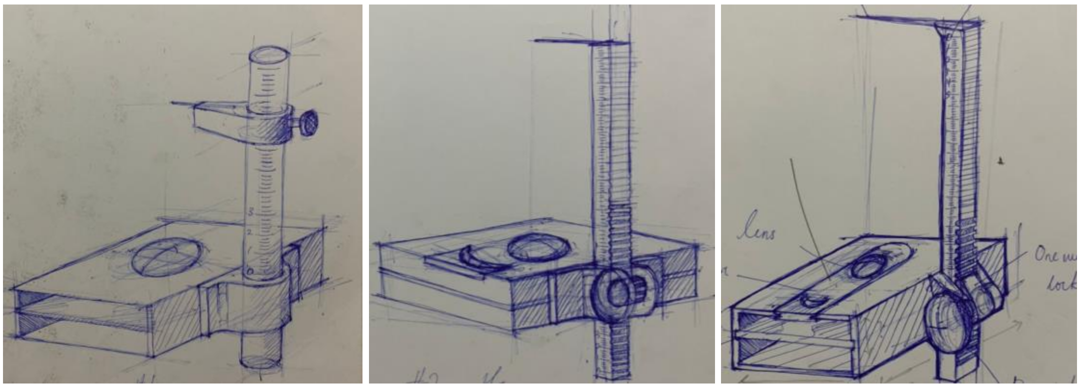


Fig 2 Concept sketches (a) sketching 1, (b) sketching 2, (c) sketching 3

2.3 Design concept

Fig 3 illustrates the anticipated design of the optical geometric experiment apparatus. This visual representation provides a detailed overview of how the experimental setup is expected to look. The diagram includes key components, their arrangements, and any specific features crucial for the optical geometric experiment.

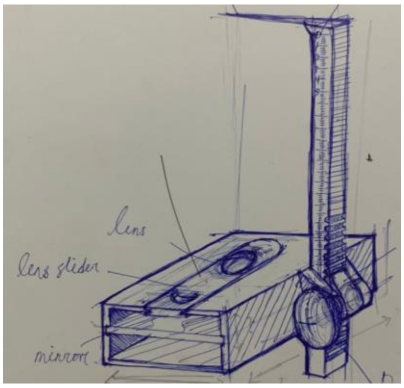
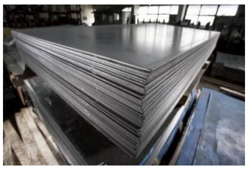
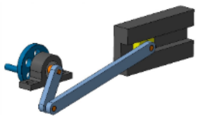


Fig 3 Expectation design

2.4 Morphological chart

A morphological chart, as outlined in Table 2, efficiently depicted potential outcomes within the product system for each functional subsystem. This chart systematically evaluated three alternatives for each function, encompassing product material and the type of mechanism. The alternatives were thoroughly analyzed to facilitate the development of a design that met the specific requirements of the geometrical optics apparatus.

Table 2 Morphological chart for geometrical optic apparatus

No	Function	Mechanism and material		
		Alternative 1	**Alternative 2**	**Alternative 3**
1	Product material	Polylactide (PLA) 	Mild steel 	Wood 
2	Type of mechanism	Screw mechanism 	Rack and pinion mechanism 	Slider mechanism 

2.5 Concept evaluation

Concept evaluation is a crucial process that assesses the value of a rated concept through grading. This evaluation involves comparison and decision-making to determine the most favorable design concepts. The primary objective is to ascertain the optimal use of resources in assessing the chosen mechanism or material for the geometrical optics apparatus. The weighted decision matrix method was employed for this purpose.

2.5.1 Weighted decision matrix

The weighted matrix is an evaluation method that assigns a total score to each design concept based on how well it meets specific criteria. In this method, each design concept is evaluated against criteria that vary in importance. The weighted decision matrix facilitates the comparison of three design concepts, as presented in Table 2. The weighted ratings of materials and components are detailed in Tables 3 and 4, contributing to the comprehensive evaluation process. This decision used Evaluating scheme for design solution [3].

Table 3 Weighted rating method product material

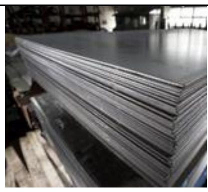
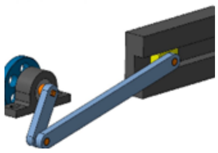
No	Criteria	Importance weightage	Polylactide (PLA)		Mild steel		Wood	
								
			Score (5-point scales)	Rating	Score (5-point scales)	Rating	Score (5-point scales)	Rating
1	Low-cost	0.225	4	0.90	3	0.675	4	0.90
2	Obtainable	0.234	4	0.936	3	0.702	3	0.702
3	Lightweight	0.193	4	0.772	2	0.386	3	0.579
4	Medium size	0.168	4	0.672	4	0.672	4	0.672
5	Anti rust material	0.189	4	0.756	3	0.567	4	0.756
	Total			4.036		3.002		3.384

Table 4 Weighted rating method of mechanism

No	Criteria	Importance weightage	Screw mechanism		Pinion and rack mechanism		Slider mechanism	
								
			Score (5-point scales)	Rating	Score (5-point scales)	Rating	Score (5-point scales)	Rating
1	Low-cost	0.225	4	0.90	3	0.675	2	0.45
2	Obtainable	0.234	3	0.702	4	0.936	2	0.468
3	Lightweight	0.193	4	0.772	3	0.579	3	0.579
4	Medium size	0.168	4	0.672	4	0.672	4	0.672
5	Anti-rust material	0.189	4	0.756	4	0.756	4	0.756
	Total			3.802		3.618		2.925

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2.5.2 Concept selection

The potential concept identified for the geometrical optics experiment apparatus comprises PLA as the product material and the pinion and rack mechanism. This choice was determined as the optimal design after careful consideration of the weighted matrix evaluations. The selected mechanism and material were compared using the weighted matrix method to determine the most favorable concept based on the design requirements.

3. Result and Discussion

This section describes the result and discussion about improving the design of optical geometric experiment apparatus.

3.1 Model sketch

Fig 4 shows the complete design of an optical geometric experiment apparatus using SolidWorks software. Fig 5 shows the tree diagram of full assembly for an optical geometric experiment apparatus. The Tree diagram was used to identify the sub assembly before proceeding to the full assembly process. The tree diagram was used to create the actual optical geometric experiment apparatus. First, there were two sub-assemblies which are main body and rack's case that need to be completed for the combination purpose to assemble the full body of the apparatus.

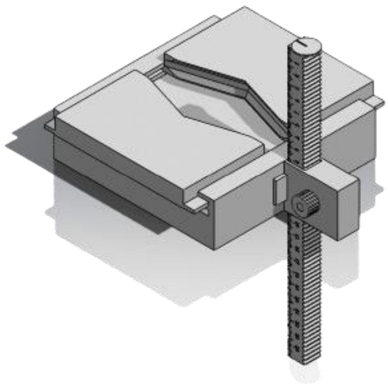

Fig 4 Full body assembly of optical geometric experiment apparatus

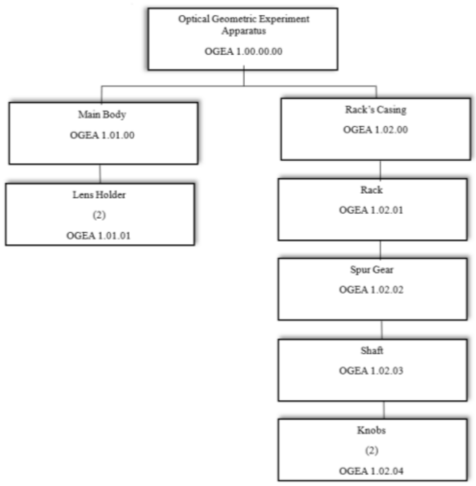

Fig 5 Tree diagram of optical geometric experiment apparatus

3.2 Manufacturing Process

3.2.1 3D Printing

The manufacturing process involved 3D printing, specifically using the Creality 3D Ender Three printer. This additive manufacturing technique facilitated the creation of three-dimensional objects layer by layer from digital models. The choice of Polylactide (PLA) as the printing material, due to its cost-effectiveness and compatibility with the apparatus's requirements, contributed to the success of the printing process. Fig 6 summarized the results of the 3D print for every component of the optical geometric experiment apparatus. The successful completion of the printing process, with details on the material used, component mass, and estimated completion time, underscored the efficiency and reliability of the chosen manufacturing method.

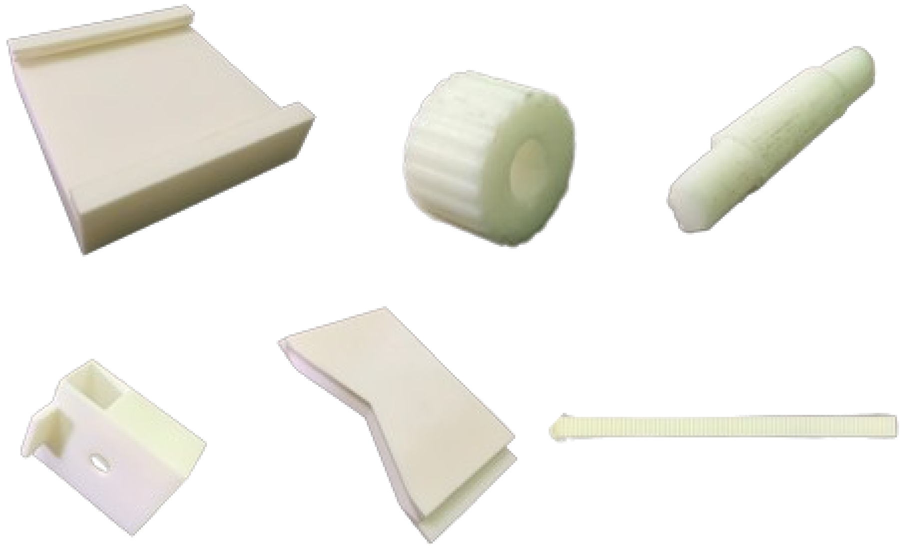

Fig 6 result of 3D printing, (a) main body, (b) knob, (c) shaft, (d) rack's case, (e) lens holder, (f) rack

3.2.2 Full Assembly of the Product

After the completion of the 3D printing process, Fig 7 showcased the complete assembly of the optical geometric experiment apparatus. The successful integration of individual components into the final product validated the efficacy of the design and manufacturing processes.

Fig 7 Complete assembly of the product

3.3 Prototype Functionally Testing

Functionality testing involved a comprehensive assessment of individual features and functions to ensure alignment with specified requirements and design. The prototype exhibited seamless operation across these parameters, meeting the intended design specifications.

3.3.1 Rack and Pinion Mechanism testing

The prototype testing focuses on evaluating the performance of its rack and pinion mechanism in adjusting length. However, it revealed a fundamental limitation the mechanism effectively measures lengths only up to 23 cm, as detailed in Table 5. This outcome serves as a conclusive declaration of the inherent constraint of the rack and pinion mechanism, establishing its maximum measuring capability at 23 cm.

Table 5 Result of rack and pinion mechanism testing

Numbers of test	Length	Result
1	10 cm	Succeed
2	20 cm	Succeed
3	25 cm	Failed

3.3.2 Lens holder testing

The prototype demonstrated successful attachment and detachment of lenses within the prescribed focal length range during the lens holder functionality test, as indicated by Table 6. However, a limitation was observed when attempting to secure lenses with diameters exceeding 10 cm, resulting in failure. It's important to note that this limitation does not impact the experiment's requirements, as the specified lens diameter is 5 cm. The data analysis highlights a critical constraint in the lens holder's capability with larger diameter lenses.

Table 4.6: Result of lens holder testing

Numbers of test	Diameter of lens	Focal length of lens	Result
1	5cm	5 cm	Succeed
2	5cm	10 cm	Succeed
3	10cm	10 cm	Succeed

3.4 Comparison data with previous apparatus

A comparative analysis was conducted between the redesigned apparatus and the previous version. The improvements in terms of user-friendliness, affordability, and overall performance were evident. Feedback from end-users, including physics teachers and students, indicated a significant enhancement in the learning experience. The redesigned apparatus effectively catered to the specific needs and preferences outlined during the interview sessions, validating the success of the redesign process. Table 5 presented the comparison data between three apparatus in determine the focal length of 5cm and 10cm diameter convex lens, retort stand, G-Optic Slider and the new design of experiment apparatus.

Table 7 Comparison data between existing apparatus

Diameter of lens	Apparatus		
	Retort stand	**G-Optic Slider**	**New design of apparatus**
5 cm	5.20 cm	4.90 cm	5.00 cm
10 cm	10.20 cm	--	10.00 cm

3.5 Costing

Table 8 presented a detailed breakdown of costs related to the optical geometric experiment apparatus, emphasizing the importance of judicious budgeting for a balance between expenditure and product quality.

Table 8 list of cost

Material	Quantity	Cost (RM)
PLA 3D Printer filament	1kg	RM 59.00
Digital Vernier Caliper	1	RM 38.00
Sandpaper (600)	1	RM 1.30
Sandpaper (800)	1	RM 1.30
Sandpaper (1000)	1	RM 1.30
Rental 3D printing machine	6 days	RM 250.00
Total		RM 350.90

4. Conclusion

In summary, this research successfully met its objectives by identifying and rectifying flaws in the existing Optical Geometric Experiment Apparatus utilized in the Pre-University Physics Course. Systematic examination revealed critical limitations in accuracy and flexibility, leading to targeted improvements in the apparatus. The redesign process resulted in a significantly enhanced device that demonstrated improved accuracy, adaptability, and user-friendliness. The development of a prototype marked a key milestone in translating theoretical enhancements into a tangible and functional tool, ultimately achieving the primary goal of aiding students in comprehending subject matter details and facilitating efficient experimentation. Beyond elevating the learning environment's quality, this project establishes a foundation for future advancements in experimental apparatus design within pre-university physics education. The enhanced Optical Geometric Experiment Apparatus serves as a testament to innovation in experimental design, poised to enhance the educational experiences of pre-university physics students. Despite these achievements, it is acknowledged that the improvement design is in its early phases, necessitating further research for refinement, particularly in challenging aspects such as patent selection and material choices.

Acknowledgement

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Adzra Ibrahim, Mohd Sharin, Choo Ley In, Abdul Ghani****; data collection****: Adzra Ibrahim, Choo Ley In, Abdul Ghani****; analysis and interpretation of results:*** *Adzra Ibrahim, Salleh Ahmad****; draft manuscript preparation:*** *Adzra Ibrahim, Salleh Ahmad. All authors reviewed the results and approved the final version of the manuscript.*

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