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Development of an Inexpensive Spectrometer Tool with a Tracker to Investigate Light Spectrum

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Abstract: One of the most fascinating areas of physics is likely optics. However, it also includes some of the phenomena that students find to be less clear-the light spectra produced by light diffraction. The experimental analysis of light spectra to evaluate radiation bodies typically requires specialized and expensive equipment that is typically out of the price range for schools. Few teachers are proficient in measuring the wavelengths of light in a spectrum. In this study, we describe a low-cost, straightforward setup that can measure light spectra accurately enough to be utilized in physics and chemistry lectures. We demonstrate how the shareware program Tracker, which is frequently used to teach mechanics, may be used to measure wavelengths with a resolution of roughly 2 nm. Several methods are also available for calibrating various setups, depending on the level of accuracy required.

Keywords: optics, spectrum, experimental, wavelength

Abstrak: *Optik mungkin adalah salah satu topik paling menarik dalam fisika. Namun, itu juga mengandung beberapa fenomena yang kurang dipahami oleh siswa-spektrum cahaya yang diperoleh dari difraksi cahaya. Studi eksperimental spektrum cahaya untuk mempelajari benda beradiasi biasanya membutuhkan peralatan canggih dan mahal yang biasanya tidak terjangkau oleh sekolah, dan hanya sedikit guru yang mengetahui cara mengukur panjang gelombang cahaya dalam spektrum. Dalam karya ini, kami menyajikan pengaturan yang sederhana dan murah, dengan akurasi yang cukup untuk mengukur spektrum cahaya yang akan digunakan baik di kelas fisika maupun kimia. Kami menunjukkan bagaimana Pelacak perangkat lunak freeware, yang biasa digunakan untuk mekanika pengajaran, dapat berfungsi untuk mengukur panjang gelombang dengan resolusi sekitar 2 nm. Beberapa pendekatan untuk kalibrasi pengaturan yang berbeda juga disediakan, tergantung pada tingkat akurasi yang diharapkan.*

Kata kunci: *optik, spektrum, eksperimental, panjang gelombang.*

▪ INTRODUCTION

The fascination that pupils have with optics and optical phenomena is well-known to us as teachers (Jannah et al., 2022). Light spectra are frequently covered in Middle and High School curricula in subjects including chemistry, optics, communications, astronomy, and biology (Nurhasnah et al., 2022). A light source's spectrum reveals a number of details about it that we may determine (Zainuddin et al., 2022). In addition to learning about the theory of light emission and viewing the emission and absorption spectra of some chemical elements (Putra, 2022), students can use some direct spectrometers to observe the many white light constituents (Herlina et al., 2022). The technique used to study the interaction between light particles and substances is called spectroscopy. If the light used is in the visible light range, the electrons will experience excitation. The interaction of light with matter is very diverse. Each substance will

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produce a different interaction with light, because each substance absorbs light at different wavelengths and intensities (Ghufron & Prayogi, 2023).

The spectrophotometer is a light-based measurement instrument that is currently widely used in various fields, physics, chemistry, pharmacy, biology, health, and geology. Spectrophotometer instruments in the field of physics are used to measure the absorbance of a material sample at a certain wavelength. Physics practicum using a laboratory scale spectrophotometer is of course very expensive and difficult to do because the tool requires extra care (Prayogi et al., 2022). Mobile phones can be utilized as simple spectrophotometer devices. The cellphone camera can capture the color spectrum in a sample, then the received light intensity can be determined.

Previous studies have developed a spectrophotometer using a DVD monochromator and light detector (Ashfaque-E-Alam et al., 2017). Research by Grasse, et al., used a cell phone detector as an image taker which then obtained data after processing using a computer (Grasse et al., 2016). Research by Bogucki, et al., developed a dual beam spectrophotometer using a 3-dimensional (3D) printer, a cellphone was used as an image taker and then measuring the intensity of the light using a computer (Bogucki et al., 2019). Bogucki's research requires a diffraction grating to change polychromatic light to monochromatic. Previous research on spectrophotometer equipment required devices that were expensive and difficult to find in Indonesia, such as diffraction gratings and light detectors.

The developed device requires a computer to measure light intensity. The mobile phone spectrophotometer can be developed to make it easy to use in Indonesia by replacing hard-to-find parts and simplifying measurements using a cell phone. The visible light mobile phone spectrophotometer product developed in this study was printed with a 3D printer and used a cell phone as a light detector. A 3D printer spectrophotometer uses almost the same spectrophotometric principles as a laboratory spectrophotometer. This tool uses polychromatic rays from sunlight or lights which are converted into monochromatic rays by reflecting them on colored paper. The monochromatic light will hit the solution. The amount of light absorbed by the solution is known as the absorbance, which is measured using the transmittance of the light received by the phone's camera. The visible spectrophotometer apparatus is very useful for use in the field concerned with the quantitative analysis of dyes based on light absorption.

Making a spectroscope today and viewing the light spectrum of either natural or artificial light is relatively straightforward (the rainbow hues) (Hamzah et al., 2022). There are many low-cost optical prisms, diffraction gratings, and recycled CDs and DVDs on the market that can divide white light into its individual hues (Hamdani et al., 2022a). However, schools are reluctant to spend a significant amount of their budget on such equipment due to spectrometers' relatively high cost (Prayogi et al., 2021). Market merchants provide spectroscopes that are reasonably priced, and allow for some measurements, but often have low precision (Roslina et al., 2022). This article shows how to build a cheap spectrometer with an acceptable degree of measurement precision using affordable components, like a commercial diffraction grating, or recycled materials, like DVDs, a digital camera, and the free video analysis tool Tracker.

▪ METHOD

This study uses the Design Based Research (DBR) research method which refers to the ADDIE model. Through the DBR method, it is hoped that it will be able to create the latest innovations in the form of learning media products that can be used in the teaching and learning process in high schools and at the university level. The steps used in the DBR research method are; 1) Analysis, 2) Design, 3) Development, 4) Implementation and Evaluation (Nichols Hess & Greer, 2016). In this study, only three stages were used, namely the analysis, design, and development stages. The type of data used in this study is descriptive data used to describe the validity level of the learning media that the researcher has created. The type of research used is qualitative-quantitative with the help of instruments to obtain all the necessary data.

The research procedure is divided into three stages, namely the analysis stage, the design stage, and the development stage. The analysis phase includes the preparation stage. Some of the activities carried out, namely analyzing the need for innovative learning media, reviewing basic competencies in instrumentation chemistry courses, analyzing chemical material to be used in making learning media, analyzing journals, determining learning media to be developed, and analyzing the needs of goods used in manufacture of inexpensive spectrometers with tracers to investigate the spectrum of light.

The design phase is the implementation stage which consists of several activities, including making flowcharts, making the initial design of a spectrometer with a simple tracer, making a storyboard, and making the components needed in a spectrometer with a simple tracer, and ending with consultation with related experts. The next stage is the development stage. The development stage consists of the initial product made by the researcher in the form of a spectrometer with a simple tracer and a validation test is carried out. This spectrometer with a simple tracer was validated by three experts from Pertamina University, Medan State University and Syiah Kuala University. From the results of the validation, suggestions for improvement and validity of the spectrometer with a simple tracer were obtained. At this stage, the preparation of research reports, data processing, and data analysis is carried out.

The data collection technique in this study was carried out by distributing validation questionnaires to three expert validators. The instruments used in the validation test include flowchart, storyboards, videos explaining the explanation of the spectrometer tool with a simple locator and validation test questionnaires. The validation test questionnaire sheet contains several indicators including, 1). Physical appearance of the spectrometer tool with a simple tracer, 2). Tool efficiency, 3). The functioning of the tool, 4). Level of practicum design implementation, 5). Security aspect, 6). Conformity with learning, 7). Economic aspects, 8). Environmental aspects.

Data analysis techniques are adjusted to the type of instrument used and the type of data obtained. The data obtained is in the form of qualitative data and quantitative data. Then data processing is carried out statistically for quantitative data and descriptive data processing for qualitative data (Sugiyono, 2010). After obtaining the data from the validation test results, a comparison analysis of the validation value with the set rcritical value is carried out. The rcritical value is generally used to identify the validity limit of an instrument which is set at 0.30 based on the use of an error rate of 5% (Miller & Miller, 2010)

- **RESULT AND DISSCUSSION**

The notion of light diffraction from a grating is an exceedingly well-explained phenomenon in any general physics text. Figure 1 shows parallel light beams that have passed through a diffraction grating and then hit a target. If D is the distance (grating spacing) seen between grating and the target, large enough to account for the parallel paths of the two rays connecting on the target, and x is the displacement (grating spacing) between point P and the main thrust O at the target plane, then represents the distance (grating spacing) seen between centers of adjacent rulings (Ikbal & Hasanah, 2022). A converging lens will concentrate the light beams from the monochromator such that they are parallel when they depart the grating because the intended use of this experiment is a camera (Fraunhofer diffraction). To verify that the rays are comparable at point P, it is not essential to know the value of D. The position of the slit image is always at Point O. (zero-order).

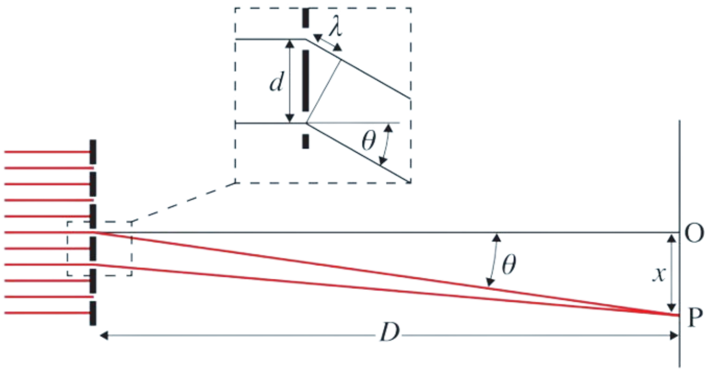

Figure 1. A diagram of the light interference on a target after passing through a diffraction grating.

The camera, which may be made out of a recycled DVD or a professional transmission diffraction grating, can operate as the spectroscope's eye (Figure 2). Spectral lines can be obtained in one of two methods. To produce a thin line spectrum, a tiny slit is cut in a grating and put in front of the light source. This is the oldest and most basic technique (Prayogi et al., 2022a). The grating is attached to the camera lens using adhesive tape. We utilized two razor blades here that were close to one another. A room must typically be darkened for this design.

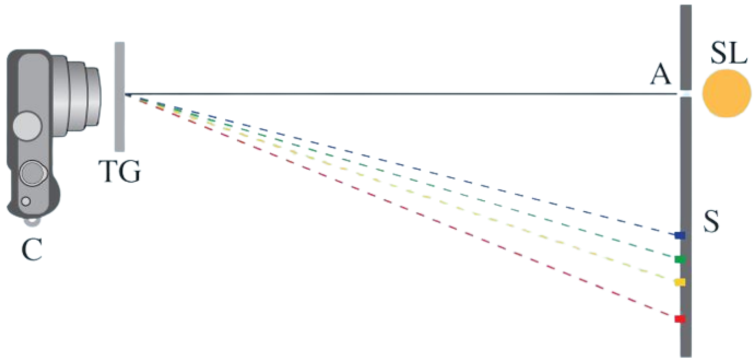

Figure 2. The fundamental experimental setup. An aperture, S screen, TG transmission grating, C digital camera, and SL spectral lamp

The other method is creating an opaque tube with a tiny slit at one end and connecting the other end of the opaque tube to the camera lens with adhesive tape to place the diffraction grating there (Figure 3). By doing this, we solve the issue of light scattering around the slit and can take stunning images of spectra even in broad daylight. It also has the benefit of just requiring the calibration process once (Triani et al., 2022).

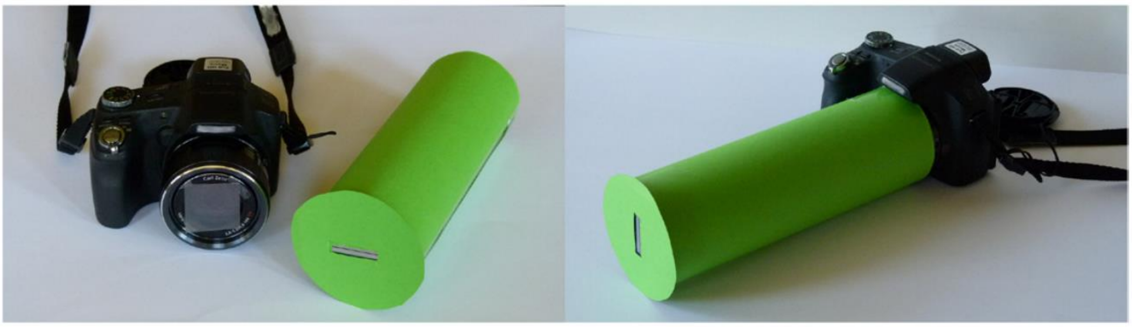

Figure 3. Images of the opaque tube with a slit at one end, the camera with the diffraction grating, and the two components combined

Figure 4 shows the examination of the spectra that were acquired for various light sources. The spectra of a mercury lamp are shown in Figure 4(b), and those of a helium lamp are shown in Figure 4(a). These spectra were used to validate the spectrometer's calibration. With a grating of 530 lines per millimeter (distance between rulings, d = 1/530 mm), the spectra were obtained.

The measuring tool Line Profile in Tracker was used to calculate the maxima light points for each spectrum (Maryani et al., 2021). The average distances between the center line and each line in the initial constructive diffraction grating for all lamps were established based on the measurement with sodium light, and the necessary wavelengths were computed. In Table 1, the results are validated by comparison to the various spectral lines mentioned in the literature.

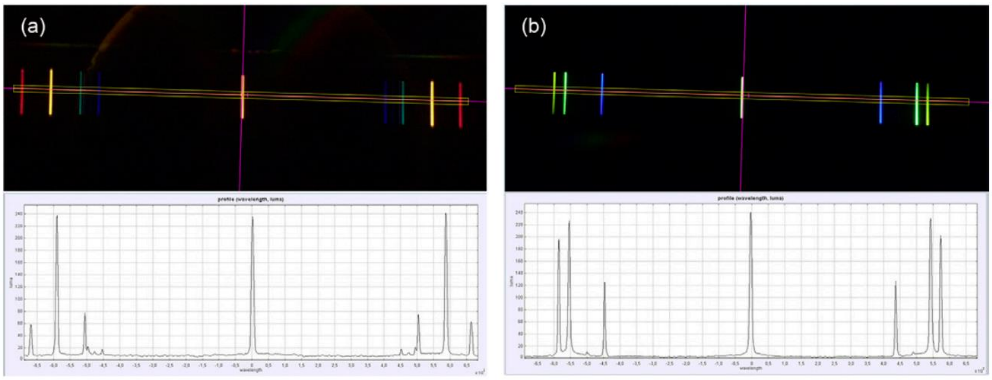

Figure 4. The spectra of a helium lamp and a mercury lamp were both obtained using a 530-line mm^{-1} grating.

Table 1. After calibrating with a sodium lamp, the spectral line wavelengths of mercury and helium lights

Mercury				Helium			
Colour	Experimental (nm)	Literature (nm)	Error (%)	Colour	Experimental (nm)	Literature (nm)	Error (%)
Blue	441	436	1.1	Blue	453	447	1.3
Green	548	546	0.4	Green	506	502	0.8
Yellow	580	579	0.2	Yellow	588	588	0.0
				Red	664	668	0.6

Once we have access to the compact fluorescent lamp spectrum, we may look at it, figure out the wavelength of each spectral line, and try to find a certain configuration of lines that would suggest the presence of a particular medication (Suyanto et al., 2021). Figure 5 demonstrates that the resulting spectra comprise pertinent lines at blue (442 nm), bright blue (492 nm), green (547 nm), yellow (587 nm), and red (612 nm). Table 2 displays the pertinent information.

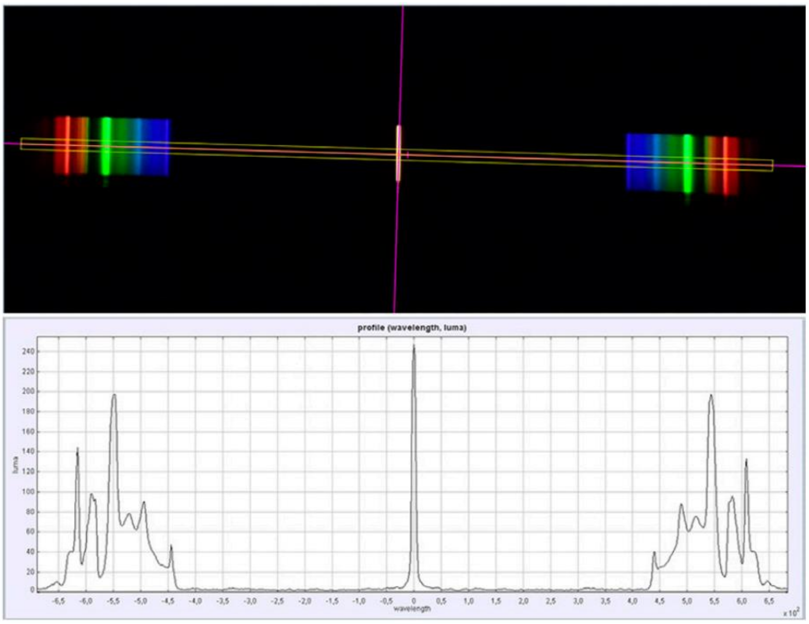

Figure 5. The spectrum of a compact fluorescent bulb is measured with a 530-line mm^{-1} grating.

Table 2. Dimensions of a tiny fluorescent light source's spectral lines after calibration with a sodium lamp

Colour	**Economizer**	**Mercury**	**Error (%)**
	Experimental (nm)	**Literature (nm)**	
Blue	442	436	1.4
Green	547	546	0.2
Yellow	587	579	1.4
Red	612		

The observations above show that the main mercury lines are readily discernible on the spectrum of fluorescent compact lights, proving that mercury is an element of these lights. This discovery has the obvious pedagogical benefit of enabling the calibration of low-cost spectrometers using common compact fluorescent bulbs (Hamdani et al., 2022b), saving schools the expense of obtaining helium, mercury, sodium, or any other expensive calibration technique.

Such spectrometers can be utilized to analyze diffraction occurrences and evaluate spectra due to their ease of use. There are several ways to use this configuration (Prayogi and Marzuki, 2022). For example, instructors can take some spectrum pictures and provide them to their students for examination. To have all of the files available in one location, the ideal approach might be to turn the photographs into a video. However, we suggest that each student or group makes their own images after some preparation and with the teacher's help (Susilawati et al., 2021). This will encourage students to take part in the experiment and, ideally, lead to a more in-depth understanding (Cullinane & Bergqvist, 2014). Better yet, students can build their own projects, use a camera or phone with it, and discuss the required specs (Diana et al., 2022). The spectrum analysis described in this study can be carried out using the tracker (Sands, 2021). Teachers must help students with their assignments in accordance with their grade level.

This experiment can be performed for a number of purposes, including (1) examining the emission light spectrum of substances and materials that serve as light sources, (2) assessing the light absorption spectrum in solutions, and (3) reflecting light off surfaces. This experiment can be carried out by teachers as a class project, as homework, or as a lab exercise. Teachers can demonstrate how a spectrometer operates while also discussing spectra and/or diffraction phenomena in the classroom.

Validation test results of the spectrometer tool with a simple tracker, the validator assesses the spectrometer tool with a simple tracker based on aspects that are contained in the validation questionnaire including aspects of appearance, safety, tool efficiency, environment, practicum design practicability, suitability with learning, and functioning/not functioning of the tool. The average rcalculated value for the validation of this simple LED spectrophotometer experimental KIT is 0.83 which is greater than the rcritical of 0.3. This shows that the simple LED spectrophotometer experimental KIT that has been made is declared valid (Sugiyono, 2010). The highest rcalculated value is 1 so that it is declared valid which is obtained from indicators of the application of the Lambert-Beer law theory and environmental indicators, namely the use of tools that can reduce the quantity of chemicals used. While the lowest rcalculated value is equal to 0.75 which is obtained from the indicator, the functioning of the tool.

The rcalculated value obtained on the design indicator of the spectrometer tool with this simple tracer has been corrected according to the suggestions from the validator. This is in accordance with the research of (Epinur, 2016) that the criteria that must be the advantages of a spectrometer with a tracker include an attractive physical appearance, not easily damaged and safe when used. The recapitulation of the validation results of the spectrometer with the tracer can be seen in Table 3.

Table 3. Recapitulation of the validation results of the spectrometer with a simple tracer

No	Assessment Indicator	$r_{calculated}$	$r_{critical}$	Results
1	*Physical appearance of the spectrometer tool with a tracker:*			
	a. The design of spectrometer with a simple tracer is interesting	0.83	0,3	Valid
	b. The series of tools are arranged in a rapport	0.92	0.3	Valid
2	*Tool efficiency:*			
	a. Easy to assemble tool	0.83	0.3	Valid
	b. Easy to use tools	0.83	0.3	Valid
	c. Easy to clean tools	0.75	0.3	Valid
	d. Easy disassembly	0.83	0.3	Valid
3	*Tool functionality:*			
	a. Generates a spectrum of colors and wavelengths for each solution	0.75	0.3	Valid
	b. Diffraction grating to determine the wavelength of visible light	0.75	0.3	Valid
	c. Gap (slit) as a part that can be removed from the device to illustrate the principle of resolution	0.83	0.3	Valid
4	*Level of practicum design implementation:*			
	a. Practicum using this tool will be easy	0.83	0.3	Valid
5	*Security aspect:*			
	a. This tool is harmless to users	0.75	0.3	Valid
	b. The basic material for making the tool is harmless to the user	0.83	0.3	Valid
6	*Compatibility with learning:*			
	a. This tool is needed in spectrophotometric analysis practicum	0.83	0.3	Valid
	b. This tool makes the practitioner more skilled and thorough	0.83	0.3	Valid
7	Economic aspect:			
	a. The cost required in making this tool is cheap	0.93	0.3	Valid
	b. The cost of making this tool can be reached by institutions and institutions	0.93	0.3	Valid
8	Environmental aspects:			
	a. The manufacture of this tool reduces the quantity of chemicals used.	1	0.3	Valid

There are several suggestions for improvement from the validator for the spectrometer with a simple tracer, namely the need to make a user manual in which the function of each component is explained and how to use the spectrometer with a tracer. This aims to facilitate the use of a spectrometer with a tracer to investigate the spectrum of light.

▪ CONCLUSION

This design was primarily made in order to provide a straightforward, reasonably priced experiment for teaching light spectra in educational settings like colleges and institutions. If a school cannot afford a reference spectra lamp like a sodium or mercury lamp, teachers can make do with a small fluorescent lamp because the principal mercury lines are clearly visible on its spectrum. Small fluorescent lamps can be used by teachers and pupils to calibrate the spectrometer. This approach has the advantage of providing a tool that anyone may create and use anywhere, whether for homework, a school project, or laboratory exercises. Even the families of the students can be shown the distinctions between various types of lighting, such as LEDs, fluorescent lamps, and street lighting. The spectroscope helps explain spectra and/or diffraction processes, explores the characteristics of light sources (consistent or discontinuous), investigates elemental light spectra (the identity card of components), and helps explain how scientists discover the material composition (for example, chemical solutions or astronomical bodies and stars). The results of the validation test of the eight aspects assessed showed a rcalculated of 0.75 with an average rcalculated of 0.83. This shows that this simple LED spectrophotometer experimental KIT is valid. Because according to theory if the rcritical value is 0.30 then the instrument is declared valid and if the rcalculated value is less than the rcritical value of 0.30 then the instrument is declared invalid. In this study, the value of rcalculated was more than 0.30 so that it could be declared valid.

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