Simulation-Based Visualization of Emission Spectrum Using a Diffraction Grating

Lira[1], Anisa Qoriq Atun Nasiroh[1], Dia Oktarina Gumanti[1], Hamdi Akhsan[1], Nadya Anggraini[1*], & Taufiq[1]
[1]Physics Education Study Program, Sriwijaya University, Indonesia
*Corresponding Author: nadyaanggraini@fkip.unsri.ac.id

Received: 12th May 2026; **Accepted**: 26th June 2026; **Published**: 30th June 2026
DOI: https://dx.doi.org/10.29303/jpft.v12i1.12092

Abstract - *This study aimed to develop a simulation-based learning medium for visualizing emission spectrum and predicting spectral colors based on the diffraction grating phenomenon. It employed a Research and Development (R&D) approach, focusing on product development, validation, and feasibility evaluation. The product was assessed through expert validation and small-group testing involving 12 students from the Physics Education Study Program. The validation results showed that the simulation was rated as highly feasible, achieving content validity of 100%, construct validity of 97.3%, linguistic and instructional clarity of 93.3%, and usability and interactivity of 93.3%, resulting in an overall validity score of 96%. These findings demonstrate that the simulation is valid and suitable as an instructional tool for teaching emission spectrum and diffraction grating concepts. As this study was limited to the product development and feasibility evaluation stages, the effectiveness of the simulation in improving students' conceptual understanding and learning outcomes remains to be investigated in future research.*

Keywords: *ADDIE model; Atomic spectrum; Diffraction grating; Simulation media*

INTRODUCTION

Spectroscopy is concerned with the study of interactions between electromagnetic radiation and the microscopic constituents (atoms and molecules) of various types of matter (Thakur, 2020). It is used to understand atomic structure and its applications across multiple fields, including elemental analysis, plasma studies, and astrophysics (Vinay Kumar, 2024). Through this process, different types of spectra can be produced, one of which is the atomic emission spectrum. An atomic emission spectrum occurs when electrons within an atom transition from a higher energy level to a lower one. This process takes place when atoms absorb energy, such as from heat or light (Ritgen, 2023), and subsequently emit photons with specific wavelengths. When we observe objects that emit or reflect light, we are essentially observing a spectrum. Light spectra have numerous applications in everyday life, such as in incandescent lamps, LEDs, and CFLs (Nayak, Parui, Sharma, & Ratha, 2020).

Light Emitting Diodes (LEDs) are semiconductor devices that emit light when an electric current passes through the p and n junction, causing electron hole recombination that releases energy in the form of photons. The wavelength of the emitted photons depends on the material's band gap energy (E_g) (Walker & Christian, 2019). LED emission offers several advantages, including high energy efficiency, long operational lifetime, and a fast response time compared to conventional light sources such as incandescent or fluorescent lamps (J. Peng et al., 2025).

In general, LEDs can be categorized into two types: narrow-spectrum (monochromatic) LEDs and phosphor-based or broad-spectrum white LEDs (David & Whitehead, 2018). Narrow-spectrum LEDs, such as red, green, or blue, produce relatively sharp emission spectra with a small spectral width (FWHM) (Bachouch et al., 2021). In contrast, broad-spectrum LEDs emit a wide and continuous spectrum that resembles natural light, making them suitable for applications such as indoor lighting, vehicle illumination, and photography.

Table 1. LED Color Spectrum

LED	λ (nm
Purple	405 – 410 (Menezes et al., 2022)
Blue	415 – 470 (Bonnans et al., 2020)
Green	495 – 530 (Lv et al., 2022; Kusuma, Pattison, & Bugbee, 2020)
Yellow	550 – 590 (Yang, Pan, Shen, & Guo, 2019)
Orange	590 – 620 (Reddy et al., 2024)
Red	600 – 700 nm (Claypool & Lieth, 2020)
Magenta	50% red light and 50% blue light (Kim et al., 2023)
White	450 – 650 (Bachouch et al., 2021)

Understanding the characteristics of a spectrum is essential to studying (Benkner, Herzog, Klir, Van Driel, & Khanh, 2022). Overall, there is an inverse relationship between wavelength and photon energy: the shorter the wavelength of a radiation, the greater the energy of the photons it carries, in accordance with the diffraction grating equation (1) (Nasiroh, Lira, Sari, & Akhsan, 2025; Kholifudin, 2017):

$$n\lambda = d\, sin\, \theta \qquad (1)$$

After obtaining the wavelength (λ), value, the photon energy can be determined using the following equation (2) (Sauerheber, 2022; Peng and Liu, 2021):

$$\Delta E = \frac{\hbar c}{\lambda} \qquad (2)$$

The photon energy is calculated using equation 2, where $\hbar$ is Planck's constant with a value of $(6{,}626 \times 10^{-34}$ J.s), c is the speed of light in a vacuum of $(3{,}0 \times 10^{8}$ m/s), and λ is the wavelength of light in meters. In diffraction analysis, d represents the grating value $(1{,}67\ \times 10^{-6}\, m)$; θ is the angle of curvature and n indicates the order of diffraction observed.

The concept of the atomic spectrum is highly important in physics education; however, it is often difficult to visualize through theory alone. Many students encounter challenges in understanding abstract concepts, particularly those related to electron transitions and emission lines (Savall-Alemany, Guisasola, Rosa Cintas, & Martínez-Torregrosa, 2019). This difficulty arises from limitations in visualizing microscopic phenomena that cannot be directly observed (Adi and Azra, 2023). Instruction that relies predominantly on mathematical approaches and theoretical explanations often becomes less meaningful for learners, thereby hindering the construction of a comprehensive conceptual understanding (Wangchuk, Wangdi, Tshomo, & Zangmo, 2023). Although diffraction gratings are well established in optical physics, intuitive visualization tools that allow users to analyze spectral formation computationally remain limited. Therefore, simulation-based approaches can play an important role as alternative optical instrumentation for spectrum analysis.

Therefore, there is a need for instructional media capable of providing concrete and interactive representations, such as spectrum simulations (Ariska, Akhsan and Zulherman, 2018;Mahfudin et al., 2021) Accordingly, this study aims to develop a simulation-based learning tool to predict spectral colors based on emission wavelengths, enabling students to better understand and visualize atomic spectrum concepts. This analysis refers to several previous studies, including:

1. A study conducted by Francisco Savall-Alemany et al., titled "Identifying student and teacher difficulties in interpreting atomic spectra using a quantum model of emission and

absorption of radiation" which discusses the difficulties experienced by high school students, physics undergraduates, and teachers in understanding atomic spectra based on quantum models (Savall-Alemany, Domènech-Blanco, Guisasola, & Martínez-Torregrosa, 2016) .
2. Research by F. Putra and L. Mardova, titled "Learning Quantum Physics: An Effort to Overcome the Difficulties of Changing Concepts in Atomic Model Materials" which examines students' challenges in understanding quantum atomic models due to the strong influence of classical physics perspectives (Putra and Mardova, 2024).
3. A study by Lana Ivanjek et al., titled "Probing student understanding of spectra through the use of a typical experiment used in teaching introductory modern physics" which identifies students' difficulties in understanding emission lines (Ivanjek, Shaffer, Planinić, & McDermott, 2020).

Previous studies have generally focused on identifying students' difficulties in understanding the concepts of atomic spectra and quantum atomic models, as well as on using experiments to assess students' understanding of spectral phenomena. However, research that develops interactive learning media integrating diffraction grating calculations, wavelength analysis, photon energy, and spectral color visualization into a single platform remains limited. In fact, it is important to fully understand the interrelationships between these concepts in modern physics education.

Various physics learning simulations, such as PhET and other spectroscopy simulation tools, have been widely used to help visualize abstract physics concepts. However, most of these simulations focus primarily on concept visualization and have not yet integrated real-time calculations of diffraction gratings, wavelength predictions, photon energy calculations, and spectral color visualization within a single learning environment. As a result, students have not yet gained a learning experience that allows them to directly connect the results of physics calculations with visual representations of the spectrum.

RESEARCH METHODS

This study employed a Research and Development (R&D) method. According to Sugiyono (Dwitiyanti, Kumala and Widiyatun, 2020) Research and Development is a method used to produce a specific product and to evaluate its effectiveness. The product developed in this research is a web-based physics simulation using Streamlit, designed to predict spectral colors based on diffraction grating phenomena within the atomic spectrum topic. The development model used for the color-prediction simulation based on diffraction grating is the ADDIE design model. The ADDIE model consists of five systematic stages (Amankwaah, Appiah-twumasi, Ateko, & Asamoah, 2024), namely needs analysis, design, development, implementation, and evaluation (Jaswadi, Maharani, Osi, & Rahayu, 2025). Visually, the stages of the ADDIE model are illustrated in Figure 1.

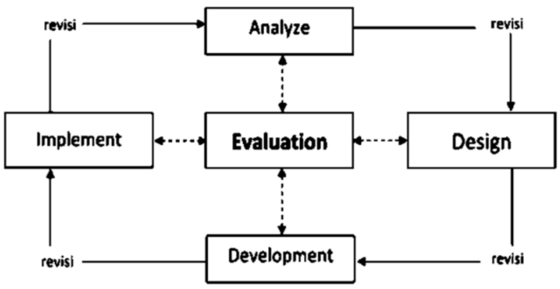

Figure 1. Flow of the ADDIE Model (Zamsiswaya, Syawaluddin and Syahrizul, 2024).

The initial stage of this research was needed analysis and literature review. The needs analysis was conducted with 65 fifth-semester Physics Education students who had previously studied wave-related topics, using a saturated sampling technique, in which the entire population was used as the research sample. Data were collected through questionnaires to identify students' levels of understanding, learning difficulties, and their needs for instructional media. In addition, a literature review was carried out by examining various relevant journals concerning learning difficulties in diffraction grating topics and the relationship between wavelength and the color spectrum.

After identifying the required specifications, the simulation structure, user interface, user interaction flow, and the algorithm for predicting color based on wavelength parameters were designed. At this stage, the main features to be included in the simulation were also determined, including wavelength input, grating constant selection, and the display of the resulting color spectrum.

The development stage involved realizing the product based on the design formulated in the previous phase. The simulation was developed using Python and the Streamlit framework, resulting in an initial product that was subsequently validated by three Physics Education experts to evaluate the content, interface, and functionality of the simulation. The validation results were used to revise and improve the product. Subsequently, the implementation stage was conducted through a small-group trial involving three groups, each consisting of four students, to obtain users' responses to the developed simulation.

The final stage in the ADDIE model is the evaluation phase, in which the outcomes of the simulation testing are assessed. This stage produces a report detailing the simulation test results. Based on the findings, the simulation is revised and improved if any system errors are identified. The data collection techniques employed in this study are as follows:

1. Needs Analysis

statements covering four aspects: difficulties in understanding the material, the need for instructional media, the need for simulation features, and interest in using simulations. Each statement was rated using a four-point Likert scale, namely Strongly Disagree (1), Disagree (2), Agree (3), and Strongly Agree (4). The questionnaire data were analyzed quantitatively using descriptive statistics in the form of percentages, calculated using the following equation:

$$P = \frac{\Sigma X}{N \times n \times S_{maxs}} \times 100\% \qquad (3)$$

2. Expert Validation

Expert validation was conducted by three Physics Education lecturers, who evaluated the developed simulation collaboratively. The assessment covered three aspects: content validity, clarity of language, and usability. The results of the expert validation were used as the basis for revising and improving the simulation before its implementation with users. The expert validation assessment criteria are presented in Table 2.

Table 2. Validator Assesssment

Assessment Percentage	Interpretation
75% - 100%	Feasible for use
50% - 75%	Feasible with revision
25% – 50%	Less feasible
0%-25%	Not feasible

The feasibility percentage of the product was calculated using Equation (4) (Khatami & Murni, 2023):

$$(\%) = \frac{\Sigma\ scores\ obtained}{\Sigma\ \text{ideal scores}} \times 100\% \qquad (4)$$

3. Small Group Trial

After the validation and revision process, the developed simulation was implemented through a small group trial. The trial involved 12 Physics Education students, who were divided into three groups, with each group consisting of four students who had previously studied wave-related topics.

The purpose of the small group trial was to investigate students' responses to the developed simulation. Students' responses were measured using a questionnaire covering the aspects of usability, visual appearance, interactivity, conceptual understanding, and learning benefit and acceptance. The percentage of students' responses was calculated using Equation (5):

$$RS(\%) = \frac{\Sigma\, student\ response\ scores}{\Sigma\ \text{maximum scores}} \times 100\% \quad (5)$$

The percentage results obtained were then interpreted according to the criteria in Table 3 to determine the level of university students' responses toward the developed simulation media.

Table 3. University Student Response Criteria

Percentage	Category
85% ≤ RS	Very positive
70% ≤ RS < 85%	Positive
50% ≤ RS < 70%	Less positive
RS < 50%	Not positive

RESULTS AND DISCUSSION

Results

Based on the results of a needs analysis involving 65 students in the Physics Education Program, the aspect of difficulty in understanding the material accounted for 89.00%, the need for learning media for 93.00%, the need for simulations for 98.33%, and interest in using simulations for 97.50%. These results indicate a need for the development of learning media capable of integrating spectrum visualization and physics calculations into a single platform to support students' understanding of atomic spectrum concepts. Therefore, the results of this needs analysis were used as the basis for designing a web-based simulation tailored to students' learning needs.

The design stage focused on developing the workflow and system structure of the web-based atomic spectrum simulation. As shown in Figure 2, a flowchart was designed to represent the operational framework of the simulation and to ensure the integration of computational and visualization features in accordance with the learning objectives.

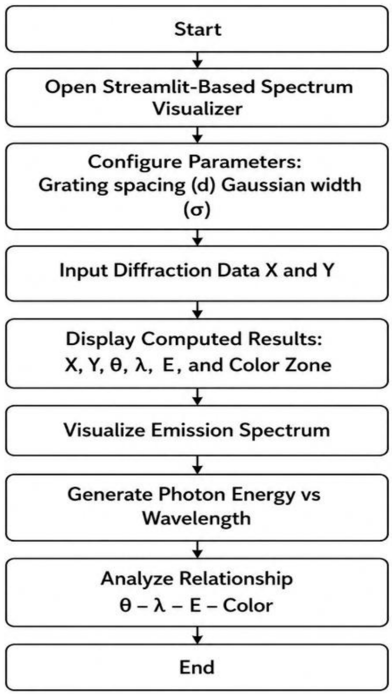

Figure 2. Flowchart of the Developed Web-Based Atomic Spectrum Simulation

The initial prototype of the web-based atomic spectrum simulation was developed using the Streamlit framework. As shown in Figure 3, the prototype provided input features for diffraction-related parameters and displayed the calculated results, including diffraction angle (θ), wavelength (λ), photon energy (E), and the corresponding light color. In addition, the simulation presented an emission spectrum visualization and a graph of photon energy versus wavelength to support students in exploring the relationships among these concepts.

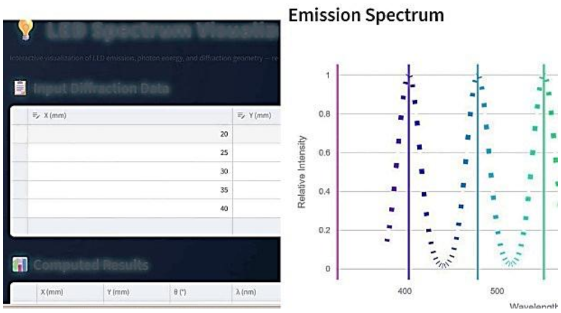

Figure 3. Initial Version of the Developed Web-Based Atomic Spectrum Simulation

The initial version of the web-based atomic spectrum simulation was evaluated by three Physics Education lecturers to assess its feasibility in terms of content validity, construct validity, clarity of language and instructions, as well as usability and interactivity. The results of the first expert validation are presented in Table 4.

Table 4. Validation Result

Validation Aspect	Percentage	Interpretation
Content validity	76.7%	Feasible for use
Construct validity	71.7%	Feasible for revision
Clarity of Language and Instructions	68.3%	Feasible for revision
Usability and Interactivity	66.7%	Feasible for revision

The first validation results indicate that the developed simulation required several revisions before implementation. Based on the evaluation, the validators provided several suggestions for improvement, as presented in Table 5.

Table 5. Suggestions from Expert Validators

Expert Suggestions
Improve the organization of interface components to create a more structured layout.
Provide clearer guidance for users when entering simulation parameters.
Enhance the emission spectrum visualization to improve conceptual understanding.
Improve the visual design by using a more attractive and consistent interface.

Following the first expert validation, several revisions were implemented to improve the quality of the simulation. The main interface was refined through a better arrangement of simulation components and information displays, as shown in Figure 4.

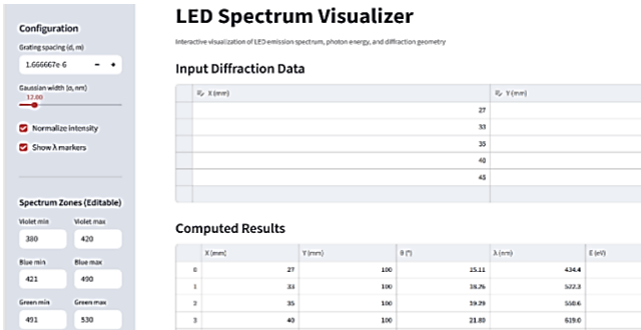

Figure 4. Main Interface of the Streamlit Application

The emission spectrum visualization was also improved to provide a more informative representation of spectral characteristics and color distribution. The revised visualization is presented in Figure 5.

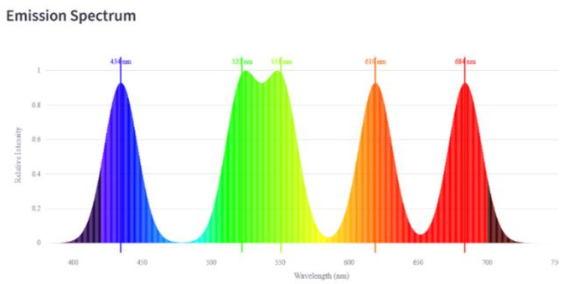

Figure 5. Revised Emission Spectrum

After revisions were made based on the suggestions and feedback from the validators, the simulation media was re-evaluated in the second stage of validation. The results fo the second stage are presented in Table 6. The validation results indicated that the developed simulation media was categorized as highly feasible, with a content validity score of 100% and a construct validity score of 97.3%. These findings demonstrate that the material, presentation flow, and media structure are well aligned with the learning objectives and are systematically organized. In addition, the aspects of clarity of language and instructions as well as usability and interactivity each obtained a score of 93.3%, indicating that the media is easy to understand and operate for users.

Table 6. Validation Result

Validation Aspect	Percentage	Interpretation
Content validity	100%	Feasible for use
Construct validity	97,3%	Feasible for use
Clarity of Language and Instructions	93,3%	Feasible for use
Usability and Interactivity	93,3%	Feasible for use

Overall, the average validation score of 96% indicates that the simulation has met the established feasibility criteria and is therefore suitable to proceed to the implementation stage to obtain users' responses to the developed media.

The web-based physics simulation was evaluated through a small group trial. The trial was conducted over three days and involved three different groups of students, with each group consisting of four students. The evaluation of the small group trial was carried out to investigate students' responses to the developed simulation, and the results are presented in Table 7.

Table 5. Student Response Analysis

Indicator	Percentage	Response Category
Usability	88.33%	Very positive
Visual	91.67%	Very positive
Interactivity	90.83%	Very positive
Conceptual Understanding	90.83%	Very positive
Learning Benefit and Acceptance	95.83%	Very positive

Based on the results of the small group trial, the web-based physics simulation received very positive responses from students across all assessment aspects. The learning benefit and acceptance aspect obtained the highest percentage at 95.83%, followed by the visual aspect at 91.67%, while the interactivity and conceptual understanding aspects each achieved 90.83%. In addition, the usability aspect also received a high percentage of 88.33%. Overall, these results indicate that the developed simulation is easy to use, visually appealing, interactive, and effective in helping students understand physics concepts. Therefore, the developed web-based physics simulation was very well accepted by students and has the potential to serve as an effective learning medium for diffraction grating and atomic spectrum topics.

Discussion

The simulation results accurately represent the relationship between the diffraction angle, wavelength, photon energy, and spectral color in accordance with the underlying theoretical principles. The wavelength and photon energy values generated by the simulation are consistent with the results of manual calculations, indicating that the computational model used has functioned properly. Furthermore, the visualization of the spectral colors corresponds to the generated wavelengths, while the resulting emission spectrum realistically depicts the distribution of light intensity.

In addition to validating theoretical calculations, the simulation developed has the potential to help students understand the abstract concept of the atomic spectrum. Through spectrum visualizations and interactive features, students can directly observe the relationship between wavelength, photon energy, spectral color, and diffraction phenomena. The integration of calculations and visualizations into a single platform allows students to connect mathematical representations with physical concepts, thereby supporting their conceptual understanding of atomic spectra.

Although the simulation results are consistent with manual calculations and have received positive feedback from users, this study is still focused on the product development and feasibility evaluation stages. Therefore, the research findings cannot yet be used to conclude the effectiveness of the simulation in improving students' conceptual understanding or learning outcomes. Testing effectiveness requires further research involving experimental designs, such as administering pretests and posttests, so that the impact of using the simulation on improving students' conceptual understanding of the atomic spectrum can be analyzed more comprehensively.

The limitations of the developed simulation are primarily related to technical and content aspects. The performance of the web application depends on internet connectivity, which may affect loading times and responsiveness. In addition, the current version presents only basic spectral color representations and does not yet cover the entire visible spectrum in detail. Future development may incorporate a broader spectral range and additional interactive features to further enhance the learning experience.

CONCLUSION

This study successfully developed an interactive Streamlit based website as a learning medium with the potential to enhance students' understanding of atomic spectrum concepts. Through interactive features that allow users to directly manipulate wavelength, photon energy, and atomic spectrum visualization, the website effectively illustrates the relationships among physical variables in an intuitive manner. Its visually appealing interface can improve students' conceptual comprehension and encourage active participation as well as two-way interaction between users and the learning material.

In the future, the development of this simulation can be directed toward integration with modern physics curricula to ensure more structured use and alignment with learning outcomes. Additionally, expanding the features to include absorption spectrum visualization and other spectroscopic phenomena may further broaden the range of concepts that can be explored. This simulation demonstrates potential application as a computational tool for optical spectrum visualization and diffraction analysis in applied physics contexts.

ACKNOWLEDGMENT

Acknowledgments are extended to the Physics Education Study Program, Faculty of Teacher Training and Education, Sriwijaya University, for the support and facilities provided, including access to relevant reference materials. Appreciation is also conveyed to the author team for their cooperation and dedication in completing this article.

REFERENCES

Adi, N. P., & Azra, F. (2023). Description of Students Learning Difficulties in Te Atomic Structure. *Jurnal Pijar Mipa*, *18*(5), 747–752. https://doi.org/10.29303/jpm.v18i5.5584

Amankwaah, D., Appiah-twumasi, E., Ateko, K. D., & Asamoah, Y. D. (2024). Efficacy of ADDIE Instructional Design in Promoting Conceptual Change in Electronic Concepts at Tano-North Municipality, Ghana. *Schrodinger:Journal of*

Physics Education, *5*(3). https://doi.org/10.37251/sjpe.v5i3.1064

Ariska, M., Akhsan, H., & Zulherman, Z. (2018). Utilization of Maple-based Physics Computation in Determining the Dynamics of Tippe Top. *Jurnal Penelitian Fisika Dan Aplikasinya (JPFA)*, *8*(2), 123. https://doi.org/10.26740/jpfa.v8n2.p123-131

Bachouch, L., Sewraj, N., Dupuis, P., Canale, L., Zissis, G., Bouslimi, L., & El Amraoui, L. (2021). An Approach for Designing Mixed Light-Emitting Diodes to Match Greenhouse Plant Absorption Spectra. *Sustainability (Switzerland)*, *13*(8), 1–16. https://doi.org/10.3390/su13084329

Benkner, S., Herzog, A., Klir, S., Van Driel, W. D., & Khanh, T. Q. (2022). Advancements in Spectral Power Distribution Modeling of Light-Emitting Diodes. *IEEE Access*, *10*(June 2022), 83612–83619. https://doi.org/10.1109/ACCESS.2022.3197280

Bonnans, M., Fouque, L., Pelletier, M., Chabert, R., Pinacolo, S., Restellini, L., & Cucumel, K. (2020). Blue light: Friend or Foe ? *Journal of Photochemistry and Photobiology B: Biology*, *212*. https://doi.org/10.1016/j.jphotobiol.2020.112026

Claypool, N. B., & Lieth, J. H. (2020). Physiological Responses of Pepper Seedlings to Various Ratios of Blue, Green, And Red Light Using LED Lamps. *Scientia Horticulturae*, *268*. https://doi.org/10.1016/j.scienta.2020.109371

David, A., & Whitehead, L. A. (2018). LED-based white light. *Comptes Rendus Physique*, *19*(3), 169–181. https://doi.org/10.1016/j.crhy.2018.02.004

Dwitiyanti, N., Kumala, S. A., & Widiyatun, F. (2020). Using the ADDIE Model in the Development of Physics Unit Conversion Application Based on Android as Learning Media. *Lppmunindra*, *10*(148), 125–132. https://doi.org/10.30998/formatif.v10i2.5933

Ivanjek, L., Shaffer, P., Planinić, M., & McDermott, L. (2020). Probing Student Understanding of Spectra Through the Use of A Typical Experiment Used in Teaching Introductory Modern Physics. *Physical Review Physics Education Research*, *16*(1). https://doi.org/10.1103/PhysRevPhysEducRes.16.010102

Jaswadi, Maharani, B., Osi, Z. S., & Rahayu, S. (2025). The Addie Learning Design Model in Physics Education Literature Review and Implementation. *Kaffah*, *1*(1).

Khatami, H., & Murni. (2023). Pengembangan Media Pembelajaran Simulasi Listrik Dinamis (SIMTRIDI) pada Platform Smartphone untuk Pembelajaran Fisika. *Jurnal Inovasi dan Pembelajaran Fisika*, 138–149.

Kholifudin, M. Y. (2017). Sinar Laser Mainan Sebagai Alternatif Sumber cahaya Monokromatik Praktikum Kisi Difraksi Cahaya. *Jurnal Penelitian Pembelajaran Fisika*, *8*(2), 129–134.

Kim, M. J., Ko, H., Kim, J. Y., Kim, H. J., Kim, H. Y., Cho, H. E., … Kang, H. C. (2023). Improvement in Yield of Extracellular Vesicles Derived from Edelweiss Callus Treated with LED Light and Enhancement of Skin Anti-Aging Indicators. *Current Issues in Molecular Biology*, *45*(12), 10159–10178. https://doi.org/10.3390/cimb45120634

Kusuma, P., Pattison, P. M., & Bugbee, B. (2020, December 1). From Physics to Fixtures to Food: Current and Potential LED Efficacy. *Horticulture Research*, Vol. 7. Springer Nature.

https://doi.org/10.1038/s41438-020-0283-7

Lv, B., Liu, Z., Chen, Y., Lan, S., Mao, J., Gu, Z., … Vasquez, H. E. (2022). Effect of Different Colored LED Lighting on the Growth and Pigment Content of Isochrysis zhanjiangensis under Laboratory Conditions. *Journal of Marine Science and Engineering*, *10*(11). https://doi.org/10.3390/jmse10111752

Mahfudin, M. A., Sunarti, T., & Jatmiko, B. (2021). Analysis of the Effectiveness Simulation-based Visual Media in Learning Physics on Students Skills and Learning Outcomes During the Covid-19 Pandemic. *International Joint Conference on Science and Engineering*, *209*, 208–213.

Menezes, C. F. S., Furtado, G. S., Sarra, G., Marques, M. M., Rodrigues, V. P., & Lago, A. D. N. (2022). Violet LED Dental Whitening: Effectiveness and Biological Safety: An in Vitro Study. *Photodiagnosis and Photodynamic Therapy*, *39*. https://doi.org/10.1016/j.pdpdt.2022.102965

Nasiroh, A. Q. A., Lira, L., Sari, I. P., & Akhsan, H. (2025). Application of Bessel Equation to Circular Slit Fraunhofer Diffraction: A Systematic Review. *EduFisika: Jurnal Pendidikan Fisika*, *10*(1), 54–64. https://doi.org/10.59052/edufisika.v10i1.42657

Nayak, A., Parui, K., Sharma, S., & Ratha, S. (2020). Study and Analysis of Atomic Spectra. *International Journal of Scientific and Research Publications (IJSRP)*, *10*(11), 946–955. https://doi.org/10.29322/ijsrp.10.11.2020.p10787

Peng, D., & Liu, K. (2021). Modeling Study of Red LED Spectral Characteristics. *Journal of Physics: Conference Series*, *1746*(1). IOP Publishing Ltd. https://doi.org/10.1088/1742-6596/1746/1/012003

Peng, J., Wang, F. F., Luo, P., Dong, X. Y., Zhang, C., & Zang, S. Q. (2025). Blue perovskite LEDs: A comprehensive review of emission Control Strategies for Enhanced Performance. *Coordination Chemistry Reviews*, *528*(January), 216425. https://doi.org/10.1016/j.ccr.2024.216425

Putra, F., & Mardova, L. (2024). Learning Quantum Physics: An Effort to Overcome the Difficulties of Changing Concepts in Atomic Model Materials. *Procedia of Social Sciences and Humanities*, 71–76. Retrieved from https://pssh.umsida.ac.id.

Reddy, S., McCartney, L., Wu, B. Sen, Addo, P. W., MacPherson, S., & Lefsrud, M. (2024). Amber Leds Outperform Red, Blue, and Red-Blue-Amber Leds for Lettuce. *Journal of Horticultural Science and Biotechnology*, *99*(6), 721–737. https://doi.org/10.1080/14620316.2024.2345894

Ritgen, U. (2023). *Analytical Chemistry I*. Rheinbach, Germany: Springer-Verlag GmbH. https://doi.org/10/1007/978-3-662-66226-3

Sauerheber, R. (2022). Potential and Kinetic Energies in Atomic Hydrogen Orbitals and Planetary Orbits, Significance of High (Near Zero) Energy Orbitals. *SSRN Electronic Journal*, (January 2022). https://doi.org/10.2139/ssrn.4098714

Savall-Alemany, F., Domènech-Blanco, J. L., Guisasola, J., & Martínez-Torregrosa, J. (2016). Identifying Student and Teacher Difficulties in Interpreting Atomic Spectra Using A Quantum Model of Emission and Absorption of Radiation. *Physical Review Physics Education Research*, *12*(1).

https://doi.org/10.1103/PhysRevPhysEducRes.12.010132

Savall-Alemany, F., Guisasola, J., Rosa Cintas, S., & Martínez-Torregrosa, J. (2019). Problem-Based Structure for A Teaching-Learning Sequence to Overcome Students' Difficulties When Learning About Atomic Spectra. *Physical Review Physics Education Research*, *15*(2), 20138. https://doi.org/10.1103/PhysRevPhysEducRes.15.020138

Thakur, S. N. (2020). Atomic emission spectroscopy. In *Laser-Induced Breakdown Spectroscopy, Second Edition* (pp. 23–40). Elsevier. https://doi.org/10.1016/B978-0-12-818829-3.00002-2

Vinay Kumar. (2024). Analysis of Atomic Structure Using Spectroscopy: An Emission and Absorption Line Spectrum Study. *International Research Journal on Advanced Science Hub*, *6*(11), 348–357. https://doi.org/10.47392/irjash.2024.046

Walker, T. D., & Christian, H. J. (2019). Triggered Lightning Spectroscopy: 2. A Quantitative Analysis. *Journal of Geophysical Research: Atmospheres*, *124*(7), 3930–3942. https://doi.org/10.1029/2018JD029901

Wangchuk, D., Wangdi, D., Tshomo, S., & Zangmo, J. (2023). Exploring Students' Perceived Difficulties of Learning Physics. *Educational Innovation and Practice*, *6*(August). https://doi.org/10.17102/eip.6.2023.03

Yang, Q., Pan, J., Shen, G., & Guo, B. (2019). Yellow Light Promotes the Growth and Accumulation of Bioactive Flavonoids in Epimedium Pseudowushanense. *Journal of Photochemistry and Photobiology B: Biology*, *197*. https://doi.org/10.1016/j.jphotobiol.2019.111550

Zamsiswaya, Syawaluddin, & Syahrizul. (2024). Pengembangan Model ADDIE (Analisys, Design, Development, Implemetation, Evaluation). *Jurnal Pendidikan Tambusai*, *8*.