

Development of a 2-D Motion Tracker Application Project Assisted By Computer Vision to Enhance Student's Laboratory Skills

Zulkarnain¹, N. W. S. Darmayanti², L. S. Utami³, Johri Sabaryati⁴, M. Isnaini⁵

¹ Universitas Muhammadiyah Mataram, Indonesia; dzul9787@gmail.com

² Institut Teknologi dan Pendidikan Markandeya, Bali, Indonesia; wyndarmayanti@gmail.com

³ Universitas Muhammadiyah Mataram, Indonesia; lindasekarutami@gmail.com

⁴ Universitas Muhammadiyah Mataram, Indonesia; joyafarashy@gmail.com

⁵ Universitas Muhammadiyah Mataram, Indonesia; iskasipahune@gmail.com

ARTICLE INFO

Keywords:

motion tracker;
projectile motion;
application project;
laboratory skills

Article history:

Received 2023-11-03

Revised 2023-11-29

Accepted 2024-03-25

ABSTRACT

The traditional lecture method, often utilized in classrooms, may limit the optimal learning experiences of students, confining their understanding to merely the theory and concepts of projectile motion. This study introduces a projectile motion tracker application as an innovative educational tool, aiming to enrich the physics learning process by enhancing students' laboratory skills. Employing a research and development (R&D) approach, the study follows the 4-D model (Define, Design, Develop, and Disseminate) to create and evaluate the application. Data were collected from 74 high school students through pre- and post-tests to measure the improvement in their laboratory skills after using the application. The evaluation utilized questionnaires and tests, indicating that the application meets high standards in language, visual design, and software engineering according to expert assessments and ranks highly in practicality for both teachers and students. The practicality was evaluated based on ease of use, attractiveness, efficiency, and usefulness. Significantly, the application has proven to enhance students' laboratory skills, as evidenced by the improvement in pre-and post-test results. Therefore, the projectile motion tracker application project emerges as a viable alternative for educators at various levels to support and invigorate physics education.

This is an open access article under the [CC BY-NC-SA](https://creativecommons.org/licenses/by-nc-sa/4.0/) license.



Corresponding Author:

Zulkarnain

Universitas Muhamamdiyah Mataram; dzul9787@gmail.com

1. INTRODUCTION

Physics education at the high school level aims to arm students with the knowledge, skills, and attitudes necessary to solve real-world problems. Despite its critical importance, the teaching approach often remains teacher-centered, focusing on memorization rather than understanding. This traditional method hampers students' ability to visualize and engage with the material, leading to a diminished interest in physics. This disengagement is compounded by the perception among students that physics is inherently difficult, a view supported by studies highlighting kinematics—and specifically projectile motion—as areas of significant challenge (Imama et al., 2021; Widodo & Widayanti, 2014; Gurusinga P., Sibarani R., 2011; Pasaribu, 2017; Erviani et al., 2016; Puspitasari & Febrinita, 2020; Khoirunnisa et al.,

2020; Swandi et al., 2021). Projectile motion, a cornerstone of kinematics, exemplifies the synthesis of two-dimensional motion, combining uniform linear motion along the horizontal axis with uniformly accelerated motion along the vertical axis. This complex interplay presents a significant conceptual hurdle for learners, underscoring the need for innovative teaching strategies that go beyond rote memorization to foster a deeper understanding and appreciation of physics principles (Khoirunnisa et al., 2020; Swandi et al., 2021).

The prevailing pedagogical approach in high school physics education, characterized by lecture-based instruction and practice problems from textbooks, has been critiqued for its teacher-centric focus. This methodology emphasizes rote memorization over comprehension, limiting students' engagement with physics theories, concepts, and formulas. Kulsum et al. (2014) argue that effective physics education should transcend mere knowledge and memorization, fostering students' ability to understand and interconnect various physics concepts. Similarly, Ilahi et al. (2021) advocate for a more participatory learning environment, where students actively explore and discover physics principles, rather than passively receiving information. The traditional lecture method, while commonly employed, falls short in facilitating an optimal learning experience, particularly in the context of understanding theoretical versus actual projectile motion. Murlin et al. (2015) propose the experimental method as a viable alternative to bridge the gap between theory and practice, enhancing students' conceptual understanding and application of physics in real-world scenarios.

The experimental method presents lessons that involve students doing experiments by experiencing and proving for themselves something to be learned (Oktaviastuti & Anggaryani, 2014). Students need laboratory skills to carry out experiments. According to Mudjiono & Dimyanti (Candra & Hidayati, 2020)), a laboratory skill approach is crucial to learning. They highlighted that laboratory skills give students first-hand experience and practical experience, and they have the power to alter their perspectives on significant issues. Laboratory skills are grouped in accordance with Swedish national standards proposed in 2005 by Grelsson and Ottander. This grouping was created following a review of the literature based on theoretical evaluation procedures and laboratory practice evaluation. Five criteria are used for assessment, namely planning experiments, conducting experiments, interpreting results, assessing outcomes, and presenting findings (Ottander, C., & Grelsson, 2006). The experimental method provides possibilities for students to take part in it firsthand in the learning process (Puryadi, 2017) through observation, experimentation, analyzing data, and comparing findings with theory. According to Subekti et al., the experimental method is a way of presenting subjects in which students actively experience and prove for themselves what they are learning so that they are totally involved in doing it themselves, proving and drawing their own conclusions about an object or physical phenomenon so that it is suitable for applying to physics learning (Subekti & Ariswan, 2016).

The experimental method is the right method to facilitate an understanding of projectile motion (Rosyanti, 2018), so projectile motion experiments that are affordable and can be easily operated by students are needed. The use of experimental tools can be optimized in the physics learning process because students can be directly involved through observation, experimentation, analyzing data, and comparing findings with theory. The limited equipment for physics experiments in schools is one of the obstacles to the non-optimal process of conveying physics concepts. On the other hand, the currently available projectile motion experimental equipment is made abroad and is quite expensive. These obstacles can be overcome by developing experimental tools for learning needs following technological developments to produce added value for students (Qomariyah et al., 2020).

Currently, there are various GUI (Guide User Interface)-based computer programs available that can be used to develop computer-assisted experimental tools. One of them is Matlab. Matlab is one of the most widely used computing tools in science and engineering. In addition to its computational speed and accuracy, Matlab also produces interesting graphics and reliable simulations. In Matlab, there are tools available to create GUIs. With a GUI, users no longer need to run their own programs through the command window. The Matlab GUI has good graphical display capabilities, and the resulting GUI file size is relatively small (Tjolleng, 2017). Matlab has the ability to integrate computing, visualization, and programming. On the other hand, Matlab is a high-capability programming

language with strong computing powers and strong visualization capabilities. (Toar-lumimuut et al., 2015). In visualizing an object, Matlab has the ability to simulate object motion (Nurullaehi, 2022) and computer vision features that can be used to track objects (Holinda Sari, 2022)(Ardiansyah et al., 2019), so this aspect can be used to develop applications project as projectile motion experiment tools. Therefore, it is necessary to develop an application project as a projectile motion experimental tool. Of course, this application project is based on a GUI supported by a computer vision system so that it is able to track projectile motion.

Numerous studies have focused on enhancing physics education through the development of computer-assisted application programs, particularly in the area of motion kinematics. Notable contributions include Swandi et al.'s (2021) interactive simulation tools for translational and circular motion, Mahmuda et al.'s (2022) bullet motion simulation media, Sari's (2013) air resistance-influenced bullet motion simulation, and Fatmawati et al.'s (2021) two-dimensional simulation of ballistic rocket motion. These projects employed a variety of programming environments, such as VBA Excel, Delphi, Pygame, and Matlab, as reported by sources including Swandi et al. (2021), Mahmuda et al. (2022), Fatmawati et al. (2021), Zulkarnain et al. (2023), Naufal et al. (2022), Rajagukguk & Sarumaha (2017), and Rustan (2021). Despite these advancements, the scope of these application programs has been predominantly confined to simulations and modeling, rendering them unsuitable for direct experimental use in physics education.

Moreover, the primary focus of these applications has been at the university level, attributed to the more prevalent use of computer software in higher education settings. Conversely, at the high school level, such technological applications are mainly utilized by educators rather than students, indicating a gap in accessibility and applicability.

This research proposes the development of an application project that leverages a graphical user interface (GUI) and incorporates computer vision technology. This innovative approach aims to transcend traditional simulations and modeling, offering a motion tracker specifically for projectile motion. This feature is designed to serve as a practical experimental tool in physics learning, thereby enhancing educational experiences. Furthermore, this study will evaluate the impact of the projectile motion tracker application on students' laboratory skills, aiming to bridge the existing gap in experimental physics education at both the high school and university levels.

2. METHODS

Development of a projectile motion tracker application program using R&D adapting the 4D model (Define, Design, Develop, and Disseminate) developed Thiagarajan et al. (1974). The subjects in this research were three high school physics teachers and 11th-grade high school students from three schools, totaling 74 students. The instrument used in this research was a questionnaire (likert scale) and test. The questionnaire was used to determine the level of validation and practicality of the projectile motion tracker application program and to measure students' laboratory skills. The validation questionnaire was given to 4 experts, consisting of 2 lecturers and 2 teachers, with the assessment aspects of the questionnaire consisting of aspects of language, visual appearance, and software engineering. The practicality questionnaire was given to 3 teachers and 74 students, with the assessment aspects of the questionnaire consisting of aspects of ease of use, attractiveness, efficiency, and usefulness. Pre-test and post-test questionnaires were given to 74 students to measure laboratory skills. A pre-test questionnaire was given before carrying out the intervention. After that, the motion tracker application project for projectile motion was demonstrated and continued by carrying out experiments aimed at determining the maximum height (y_{max}) and maximum reach (x_{max}). A post-test questionnaire is then presented to the students to measure their laboratory skills. The data obtained were analyzed using descriptive analysis techniques. Validation test result data is interpreted based on scores and assessment criteria as in Table 1, while practicality test result data is interpreted based on scores and evaluation category, as shown in Table 2.

Table 1. Validation stage Category.

Score Interval (%)	Category
81 - 100	Very Good
61 - 80	Good
41 - 60	Pretty Good
21 - 40	Not Good
0 - 20	Not Very Good

Table 2. Practicality stage Category.

Score Interval (%)	Category
$85 < P \leq 100$	Very Practical
$75 < P \leq 85$	Practical
$59 < P \leq 75$	Pretty Practical
$54 < P \leq 59$	Not Practical
≤ 54	Not Very Practical

In determining students' laboratory skills, grade ranges and criteria are used as in Table 3, followed by the N-Gain test developed by Hake, (1999) for further analysis of pre-test and post-test data with scores and evaluation category as in Table 4.

Table 3. Student Laboratory's Skills Category.

Score Interval	Category
$3.33 < \text{score} < 4.00$	Very Good
$2.33 < \text{score} < 3.33$	Good
$1.33 < \text{score} < 2.33$	Enough
$\text{score} \leq 1.33$	Less

Table 4. N-Gain Score Category.

Score Interval	Category
$(g) \geq 0.7$	High
$0.7 > (g) \geq 0.3$	Moderate
$(g) < 0.3$	Low

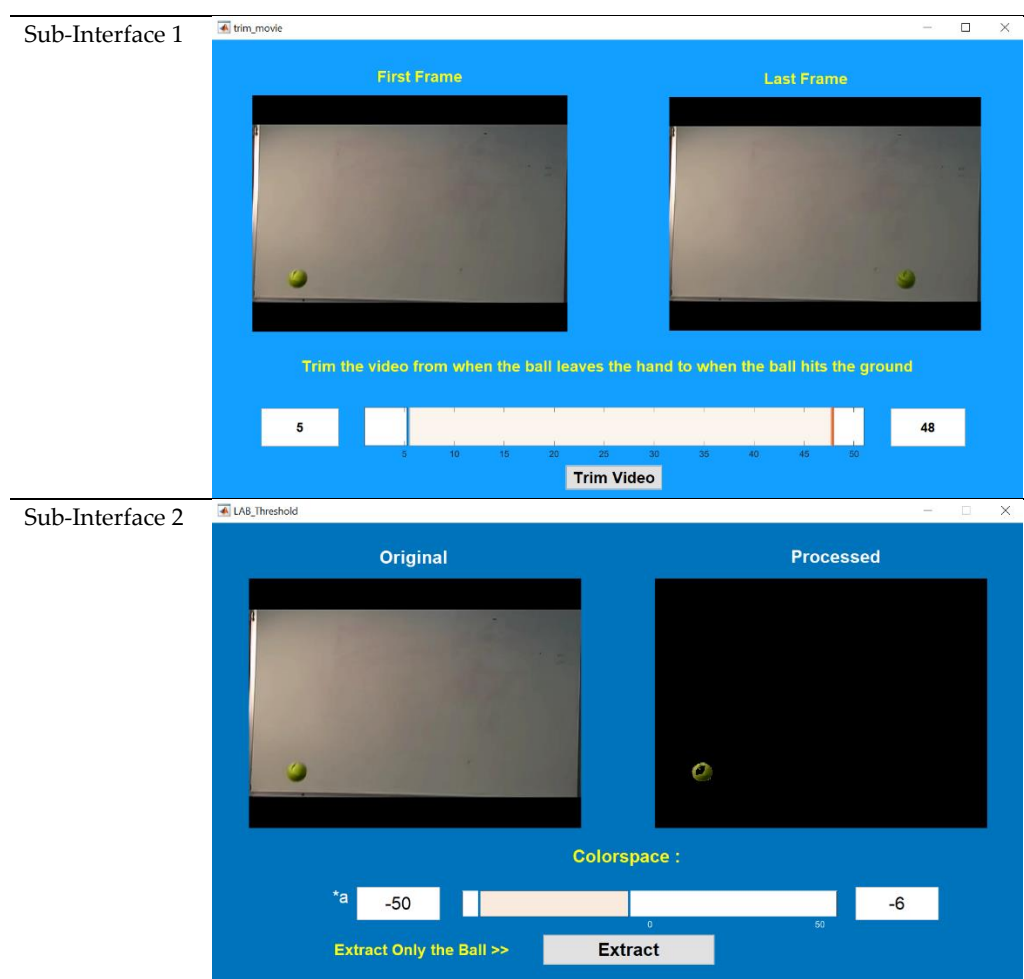
3. FINDINGS AND DISCUSSION

The product developed in this research was a projectile motion tracker application program. The application program was computer-based and can be employed as a tool for physics education. This application program consists of a splash screen, a main interface, and two sub-interfaces whose appearance and parts can be seen in Table 5.

The splash screen is the initial display of the application program every time the application is run. The main interface is a display that contains four panels along with the attributes contained therein, such as buttons, graphs, and data entry fields. In the main interface, there are two menus: (1) the Language menu, which is a menu that provides options for users to choose to use Indonesian or English for written text when running the application, and (2) the Guide menu, which provides options for the user to select a user guide in Indonesian or English that will appear in PDF format when executed.

Table 5. Product Layout

Section	Design
Splash screen	 <p>The splash screen features the application title 'PROMOTRACK Projectile Motion Tracker' in blue and black text. Below the title, it indicates 'Version 1.0'. The background consists of a white grid pattern and a 3D graphic of a blue and red curved surface.</p>
Main Interface	 <p>The main interface is divided into several functional areas:</p> <ul style="list-style-type: none"> 1. VIDEO: Contains an 'Import Video' button, a 'Detect Ball' button, and a video player showing a projectile's path. 2. CONVERT [Pixel] >> [cm]: Includes a 'Measure Pixel Length' button, input fields for 'Length (pixel)' (value: 390.2439) and 'Length (cm)' (value: 50), and a 'Convert to [cm]' button. 3. ANALYSIS: Displays three graphs: <ul style="list-style-type: none"> Horizontal (cm) vs Time (sec): A linear graph showing constant horizontal velocity. Vertical (cm) vs Time (sec): A parabolic graph showing constant vertical acceleration. Vertical (cm) vs Horizontal (cm): A parabolic graph showing the trajectory of the projectile. 4. CHECK DATA: A yellow button labeled 'Read Off Data Coordinates'.



Media experts validated the final product of the projectile motion tracker application project to test its validity. The results of the expert validation can be seen in Table 6.

Table 6. Expert Validation Results.

Aspect	V1	V2	V3	V4	Average	Validity Score (%)	Validity Criteria
Language	4	5	4.33	5	4.58	91.67	Very Good
Visual Appearance	4.25	4.25	4.63	4.75	4.47	89.38	Very Good
Software Engineering	4.75	4,25	4.75	5	4.69	93.75	Very Good
				Total	13.74	274.8	
				Average	4.58	91.6	Very Good

Based on Table 6, the assessment from four experts gave an average of 4.58 with a percentage score of 91.6. So it can be concluded that the projectile motion tracker application project is in the very good category in terms of language, visual appearance, and software engineering. Suggestions and revisions from experts as shown in Table 7.

The next stage is to carry out practicality tests on users consisting of three physics teachers and 74 students. The results of practicality tests by users can be seen in Tables 8 and 9. Based on Table 8, the results of the practicality test gave an average of 4.42 with a percentage score of 88.4, so it can be concluded that the projectile motion tracker application program is in the very practical category. This means that the application program developed is easy to use, attractive, efficient, and useful.

Table 7. The Suggestions and Revisions Given by Experts

Suggestions	Before Revision
1. The background color on panel 1 feels more contrasting; it's best to use a lighter color.	
2. User manual are not yet available; add the user manual menu.	
	After Revision

Table 8. Teachers Practicality Results

Aspect	T1	T2	T2	Average	Practicality Score (%)	Practicality Criteria
Ease of Use	4.25	4.75	4.75	4.58	91.67	Very Practical
Attractiveness	4.5	4.25	4.75	4.5	90	Very Practical
Efficiency	4	4.5	4.5	4.33	86.67	Very Practical
Usefulness	4.4	4.2	4.2	4.27	85.33	Very Practical
	Total			17.68	353.67	Very Practical
	Average			4.42	88.4	

Table 9. Students Practicality Results

Aspect	S1	S2	S3	Average	Practicality Score (%)	Practicality Criteria
Ease of Use	4.39	4.53	4.46	4.46	89.2	Very Practical
Attractiveness	4.69	4.56	4.52	4.57	91.45	Very Practical
Efficiency	4.30	4.5	4.41	4.40	88.1	Very Practical
Usefulness	4.28	4.46	4.39	4.38	87.6	Very Practical
	Total			17.81	356.35	Very Practical
	Average			4.45	89	

Based on Table 9, the results of the practicality test gave an average of 4.45 with a percentage score of 89, so it can be concluded that the projectile motion tracker application program is in the very practical category. This means that the application program developed is easy to use, attractive, efficient, and useful. The criteria shown by both the teacher and student practicality test results show that the projectile motion tracker application program developed can be used in physics learning because it has very practical value in all aspects.

Upon being reported valid by experts and very practical by users (teachers and students), the effectiveness of the projectile motion tracker application project was tested. The effectiveness test was conducted to measure students' laboratory skills using the N-Gain score and pretest and posttest results before and after using the projectile motion tracker application project. The results can be seen in Table 10.

Table 10. Laboratory Skills Score and N-Gain Score

Criteria	Before	After	N-Gain	Criteria
Planning Experiments	1.37	2.19		
Conducting experiments	1.37	2.10		
Results Interpretation	1.3	2.15	0.61	Moderate
Outcomes Assessment	1.31	2.25		
Presentation of Findings	1.28	2.05		

Table 10 shows that there is an increase in students' laboratory skills, which is reinforced by laboratory skills data where all assessment criteria have increased. Furthermore, the N-Gain score of 0.61 indicates the projectile motion tracker application program is efficient in enhancing students' laboratory skills.

The motion tracker application project represents a user-friendly, visually appealing, effective, and practical program developed through meticulous data analysis. Its efficacy has been noted in enhancing students' proficiency in laboratory settings. Both before and after using the projectile motion tracker application, students have demonstrated improvements in their skills, with the most significant enhancement observed in the medium category, boasting an N-Gain score of 0.61. These applications empower students to actively pursue outcomes and enhance their understanding of the taught material. According to Candra & Hidayati (2020), a laboratory skill approach is fundamental to learning, providing students with real-world experience, practical application, and the ability to reshape their perspectives on significant issues.

While various studies have explored the creation of teaching materials, each study possesses unique characteristics that distinguish it from others. These distinctions encompass the materials covered, the methodologies employed, and the applications utilized. Diverse applications utilized for learning facilitate students' comprehension of the educational materials (Nasution, 2018).

For instance, research conducted by Akçayir et al. (2016) titled "Augmented Reality in Science Laboratories: The Effects of Augmented Reality on University Students' Laboratory Skills and Attitudes Toward Science Laboratories" found that employing AR applications positively impacted students' laboratory skills. A pretest and posttest analysis indicated notable improvements, with a t-test of 1.73 for the pretest and 2.43 for the posttest. Unlike the current study, this research utilized AR applications (android-based) and focused on Wheatstone bridges.

Similarly, the study conducted by Prastya et al. (2023) exhibited significant enhancement in students' laboratory skills. Employing the Borg and Gall development model, the study obtained validation results indicating a high level of quality. Additionally, teacher and student responses indicated a favorable perception of the product's effectiveness. With an N-Gain score of 0.56, the product significantly contributed to enhancing students' laboratory skills. Unlike the previous study, this research utilized an AR application (android-based) and focused on geometrical optics. Moreover, it utilized the Borg and Gall development model.

In summary, while several studies explore the development of teaching materials, each study offers distinct insights influenced by the materials covered, methodologies employed, applications utilized, and development models applied. These nuances highlight the diverse approaches in enhancing students' learning experiences.

4. CONCLUSION

Based on the findings from the conducted research, the projectile motion tracker application program demonstrated promising outcomes throughout its various evaluation stages. During the expert validation phase, the program received an impressive average score of 4.58, equivalent to 91.6%, indicating its placement within the very good category. Subsequently, during the practical testing by teachers, an average score of 4.42 (88.4%) was achieved, and from student evaluations, an average score of 4.45 (89%) was attained. These results collectively position the projectile motion tracker application program within the very practical category. Moreover, the effectiveness test exhibited notable enhancements in students' laboratory skills, evident from the moderate N-Gain score of 0.61. This indicates a significant improvement attributed to the application's implementation. As a result, the projectile motion tracker application stands as a valuable innovation and alternative to conventional teaching methodologies in physics education. However, certain limitations were identified within the application project. Firstly, it lacks an automatic measurement feature for the elevation angle. Secondly, there is no provision for comparing theoretical and experimental results within the program's layout. Additionally, comprehensive application usage instructions are necessary. In conclusion, while the projectile motion tracker application project displays considerable strengths and benefits, addressing these identified limitations will further enhance its utility and effectiveness in facilitating physics learning.

Acknowledgments: This research was funded by a PDP 2023 research grant from the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia [contract number 184/E5/PG.02.00.PL/2023].

REFERENCES

- Akçayir, M., Akçayir, G., Pektaş, H. M., & Ocak, M. A. (2016). Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories. *Computers in Human Behavior*, 57, 334–342. <https://doi.org/10.1016/J.CHB.2015.12.054>
- Ardiansyah, N. F., Rabi', A., Minggu, D., & Dirgantara, W. (2019). Computer Vision Untuk Pengenalan Obyek Pada Peluncuran Roket Kendaraan Tempur. *JASIEK (Jurnal Aplikasi Sains, Informasi, Elektronika Dan Komputer)*, 1(1). <https://doi.org/10.26905/jasiek.v1i1.3142>
- Candra, R., & Hidayati, D. (2020). Penerapan Praktikum dalam Meningkatkan Keterampilan Proses dan Kerja Peserta Didik di Laboratorium IPA. *Eduagama: Jurnal Kependidikan Dan Sosial Keagamaan*, 6(1), 26–37. <https://doi.org/https://doi.org/10.32923/edugama.v6i1.1289>
- Erviani, F. R., Sutarto, & Indrawati. (2016). Model Pembelajaran Instruction, Doing, dan Evaluating (MPIDE) Disertai Resume dan Vdeo Fenomena Alam dalam Pembelajaran Fisika di SMA. *Jurnal Pembelajaran Fisika*, 5(1).
- Fatmawati, F., Sofyan, E., & Eko Prasetyo, E. (2021). PEMODELAN DAN SIMULASI GERAK DUA DIMENSI ROKET BALISTIK 122. *Teknika STTKD: Jurnal Teknik, Elektronik, Engine*, 7(2). <https://doi.org/10.56521/teknika.v7i2.323>
- Gurusinga P., Sibarani R. (2011). Analisis Rata-rata Nilai Fisika dengan Metode Ekspositori dan Inkuiri. *Jurnal Ilmiah Satya Negara Indonesia*, 4(2), 28–36.
- Hake, R. R. (1999). Analyzing change/gain scores. *Unpublished.[Online] URL: Http://Www. Physics. Indiana. Edu/~ Sdi/AnalyzingChange-Gain. Pdf.*
- Holinda Sari, E. (2022). Sistem Tracking Multi Object Yang Bergerak Di Jalan Raya Dengan Metode Frame Difference Dan Edge Detection. *Jurnal Impresi Indonesia*, 1(9). <https://doi.org/10.36418/jii.v1i9.456>
- Ilahi, T. D. W., Mufit, F., Hidayati, H., & Afrizon, R. (2021). Disain dan Validitas Multimedia Interaktif Berbasis Konflik Kognitif pada Materi Vektor untuk Kelas X SMA/MA. *Jurnal Penelitian Pembelajaran Fisika*, 12(2). <https://doi.org/10.26877/jp2f.v12i2.9324>
- Imama, N., Sutarto, S., & Harijanto, A. (2021). Model Pembelajaran Dengan Kegiatan Mendeskripsikan Demonstrasi Secara Konseptual Dalam Pembelajaran Fisika SMA. *Jurnal Pendidikan Fisika*, 3(2).

- Khoirunnisa, I., Linuwih, S., Fisika, J., Matematika, F., Ilmu, D., & Alam, P. (2020). Penerapan Pembelajaran Contextual Teaching and Learning (CTL) untuk Meningkatkan Pemahaman Konsep Siswa Tahfidz dan Reguler Materi Gerak Parabola. *Unnes Physics Education Journal*, 9(2). <https://doi.org/https://doi.org/10.15294/upej.v9i2.41915>
- Kulsum, U., & Nugroho, S. (2014). Penerapan Model Pembelajaran Cooperative Problem Solving untuk Meningkatkan Pemahaman Konsep dan Komunikasi Ilmiah Siswa pada Mata Pelajaran Fisika. *UPEJ Unnes Physic Education Jurnal*, 3(2). <https://doi.org/https://doi.org/10.15294/upej.v3i2.3600>
- Mahmuda, M., Nafaida, R., Mustika, D., & Saputra, H. (2022). Media Simulasi Gerak Peluru Menggunakan VBA Excell Dalam Pembelajaran Fisika Pada Materi Gerak Parabola. *Jurnal Pendidikan Fisika Dan Sains*, 5(2). <https://doi.org/https://doi.org/10.33059/gravitasi.jpfs.v5i02.6490>
- Murlin, A., Tawil, M., & Samad, A. (2015). Penerapan Metode Pembelajaran Eksperimen dengan LKPD Terstruktur Terhadap Peningkatan Hasil Belajar Fisika Peserta Didik Kelas X SMA Negeri 2 Sukamaju. *Jurnal Pendidikan Fisika*, 3(2). <https://doi.org/https://doi.org/10.26618/jpf.v3i2.265>
- Nasution, S. H. (2018). Pentingnya literasi teknologi bagi Mahasiswa Calon Guru Matematika. *Jurnal Kajian Pembelajaran Matematika*, 2(1), 14–18. <https://doi.org/http://dx.doi.org/10.17977/um076v2i12018p14-18>
- Naufal, M., Wiyuna, T., Bintarum, A. D., & Burhanudin, A. F. (2022). Desain Simulasi Gerak Parabola Sebagai Pemanfaatan Pembelajaran Fisika SMA Kelas X Menggunakan Pygame. *Mitra Pilar: Jurnal Pendidikan, Inovasi, Dan Terapan Teknologi*, 1(2). <https://doi.org/10.58797/pilar.0102.08>
- Nurullaeli, N. (2022). Media Analisis Dan Simulasi Gerak Menggelinding Di Bidang Datar Berbasis Matlab. *Semnas Ristek (Seminar Nasional Riset Dan Inovasi Teknologi)*. <https://doi.org/10.30998/semnasristek.v6i1.5817>
- Oktaviastuti, R., & Anggaryani, M. (2014). Implementasi Metode Eksperimen dalam Pembelajaran Fisika sebagai Upaya Melatihkan Keterampilan Proses Sains Siswa Kelas XI di SMA Wachid Hasyim 2 Taman Sidoarjo. *Jurnal Inovasi Pendidikan Fisika*, 3(1). <https://doi.org/https://doi.org/10.26740/ipf.v3n1.p%25p>
- Ottander, C., & Grelsson, G. (2006). Laboratory work: the teachers' perspective. *Journal of Biological Education*, 40(3), 13–118. <https://doi.org/https://doi.org/10.1080/00219266.2006.9656027>
- Pasaribu, D. S. (2017). Upaya Meningkatkan Minat Dan Hasil Belajar Fisika Siswa Dengan Menggunakan Model Pembelajaran Talking Stick Pada Materi Listrik Dinamis Di Kelas X Sman 10 Muaro Jambi. *EduFisika*, 2(1). <https://doi.org/https://doi.org/10.22437/edufisika.v2i01.4043>
- Prastya, B. M. Y., Sri, B., & Daru, W. (2023). Development Of Physics Learning Media PHY-ART (Physics With Augmented Reality Technology) To Empower Student's Laboratory Skills. *JIPF (JURNAL ILMU PENDIDIKAN FISIKA)*, 8(2), 192–199. <https://doi.org/http://dx.doi.org/10.26737/jipf.v8i2.3730>
- Puryadi. (2017). Implementation Of Experiment Method To Increase Study Attitudes And Student Learning Achievements. *DIADIK: Jurnal Ilmiah Teknologi Pendidikan*, 7(2). <https://doi.org/https://doi.org/10.33369/diadi.v7i2.3691>
- Puspitasari, W. D., & Febrinita, F. (2020). Persepsi mahasiswa tentang pemahaman konsep kinematika gerak ditinjau dari kemampuan berpikir kritis. *UPEJ Unnes Physics Education Journal*, 9(2). <https://doi.org/https://doi.org/10.15294/upej.v9i2.41927>
- Qomariyah, N., Wirawan, R., Minardi, S., Alaa', S., & Yudi Handayana, I. G. N. (2020). Pendalaman Konsep Fisika Menggunakan Alat Peraga Berbasis Mikrokontroler Pada Siswa SMA. *SELAPARANG Jurnal Pengabdian Masyarakat Berkemajuan*, 4(1). <https://doi.org/10.31764/jpmb.v4i1.3225>
- Rajagukguk, J., & Sarumaha, C. (2017). Pemodelan Dan Analisis Gerak Parabola Dua Dimensi Dengan Menggunakan Aplikasi Gui Matlab. *Jurnal Saintika*, 4(4). <https://doi.org/https://doi.org/10.24114/jiaf.v4i4.11378>
- Rosyanti, a. (2018). Pengaruh metode eksperimen dengan menggunakan alat peraga terhadap hasil belajar peserta didik kelas x sma negeri 1 lhoong aceh besar pada materi gerak parabola. Universitas Islam Negeri Ar-Raniry Banda Aceh.

- Rustan, R. (2021). Pemodelan Gerak 2 Dimensi Berbasis GUI Matlab dengan Ketinggian Awal Tertentu. *Radiasi : Jurnal Berkala Pendidikan Fisika*, 14(2). <https://doi.org/10.37729/radiasi.v14i2.1288>
- Sari, S. R. (2013). Simulasi Gerak Peluru Yang Dipengaruhi Gaya Hambat Udara Beserta Analisisnya Dengan Menggunakan Bahasa Pemrograman Delphi 7.0. *Inovasi Fisika Indonesia*, 2(1), 0–4. <https://doi.org/https://doi.org/10.26740/ifi.v2n1.p%25p>
- Subekti, Y., & Ariswan, A. (2016). Pembelajaran Fisika dengan Metode Eksperimen untuk Meningkatkan Hasil Belajar kognitif dan Keterampilan Proses Sains. *Jurnal Inovasi Pendidikan Ipa*, 2(2). <https://doi.org/https://doi.org/10.21831/jipi.v2i2.6278>
- Swandi, A., Rahmadhanningsih, S., Viridi, S., Nurhayati, N., Putri, R. A., & Suryadi, A. (2021). Simulasi Gerak Translasi Dan Gerak Melingkar Menggunakan Vba Macro Excel Melalui Project Based Learning (Pbl). *JPF (Jurnal Pendidikan Fisika)*, 9(1), 33. <https://doi.org/10.24252/jpf.v9i1.20519>
- Thiagarajan, S., Semmel, D. S., & Semmel, M. I. (1974). Instructional Development for Training Teachers of Exceptional Children. Washinton DC: National Center for Improvement Educational System. *Education Resources Information Center (ERIC)*.
- Tjolleng, A. (2017). *Pengantar Pemrograman Matlab*. Elex Media Komputindo.
- Toar-lumimuut, Tolah, R. E. P., Sengkey, R., & Rindengan, Y. D. Y. (2015). Perancangan Simulasi Otomatis Traffic light Menggunakan Citra Digital Studi Kasus. *E-Journal Teknik Elektro Dan Komputer*, 4(4). <https://doi.org/https://doi.org/10.35793/jtek.v4i4.8971>
- Widodo., & Widayanti, L. (2014). Peningkatan Aktivitas Belajar dan Hasil Belajar Siswa dengan Metode Problem Based Learning pada Siswa Kelas VIIA MTs Negeri Donomulyo Kulon Progo Tahun Pelajaran 2012/2013. *Jurnal Fisika Indonesia*, 17(49). <https://doi.org/10.22146/jfi.24410>
- Zulkarnain, Z., Islahudin, I., Isnaini, M., Utami, L. S., Anwar, K., & Darmayanti, N. W. S. (2023). Project 2-D Motion Simulation Based on Matlab Graphical User Interface in Physics Learning. *Radiasi : Jurnal Berkala Pendidikan Fisika*, 16(1), 9–16. <https://doi.org/10.37729/radiasi.v16i1.2149>