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Development of Combinatorial Optimization Models with Discrete Mathematics Methods in Mathematical Physics Courses

Astalini[1], Luis Roberto Pino-Fan[2], Somjai Boonsiri[3], U.L. Zainudeen[4], Tin Nwe Aye[5], Duong Vu[6]
[1]Physics Education, Faculty of Teacher Training and Education, Universitas Jambi, Indonesia
[2]Departamento de Ciencias Exactas, Universidad de Los Lagos, Osorno, Chile
[3]Department of Mathematics and Computer Science, Faculty of Science, Chulalongkorn University, Thailand
[4]Department of Physical Sciences, Faculty of Applied Sciences, South Eastern University of Sri Lanka
[5]Department Mathematics, Kyaukse University, Myanmar
[6]Institute of Physics, Vietnam Academy of Science and Technology, Vietnam

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ABSTRACT

Purpose of the study: This research aims to develop a combinatorial optimization model based on discrete mathematical methods that can be applied to mathematical physics problems in complex systems, such as molecular energy configurations and viscoelastic system simulations.

Methodology: The study used a development approach with ADDIE design (Analysis, Design, Development, Implementation, Evaluation). Data were obtained through interviews, simulations, and instrument validation involving lecturers and students of mathematical physics.

Main Findings: The results of the study showed that the developed model had an average accuracy of 85% and a time efficiency of 2.5 seconds per iteration. This model also received positive feedback from users, with an average satisfaction score of 4.6 out of 5.

Novelty/Originality of this study: The novelty of the research lies in the integration of discrete mathematical methods with combinatorial optimization to solve complex mathematical physics problems.

Corresponding Author:
Astalini,
Physics Education, Faculty of Teacher Training and Education, Universitas Jambi, Indonesia
Jl. Jambi – Muara Bulian No.KM. 15, Mendalo Darat, Jambi, 36361, Indonesia
Email: astalinizakir@unja.ac.id

1. INTRODUCTION

In higher education, mathematical physics is one of the disciplines that combines the principles of mathematics and physics to analyze complex natural phenomena. This course not only equips students with an understanding of basic concepts, but also trains critical and analytical thinking skills [1]-[3]. One of the major challenges in mathematical physics is how to deal with complex system problems, such as energy configuration analysis, viscoelastic material behavior, or particle interactions in dynamic systems [4], [5]. In this context, the development of optimization methods based on discrete mathematics becomes very relevant to soslve these problems [6]-[8].

Discrete mathematics, with the scope of combinatorics, graph theory, and algorithms, offers an effective approach to dealing with optimization problems that often arise in mathematical physics [9], [10]. This approach allows for structured and systematic analysis of complex systems, especially those involving large data structures and interdependent variables [11]-[13]. However, conventional optimization methods are often less adaptive to problems that require high complexity modeling, so it is necessary to develop new, more effective approaches.

One potential method to overcome these challenges is the development of a combinatorial optimization model based on discrete methods that utilize combinatorics theory. By integrating elements of fractional calculus, this approach is not only able to handle systems with many variables but also provides more accurate and efficient solutions [14]-[16]. Such models are expected to provide breakthroughs in complex system analysis, which ultimately supports mathematical physics learning in universities [17]-[19].

The research methodology used includes several main stages, namely complex system requirements analysis, optimization model design based on combinatoric theory, mathematical algorithm development, model implementation in real case studies, and model performance evaluation [20]-[22]. This research is quantitative in nature by measuring the accuracy, time efficiency, and model performance using relevant numerical data. With this approach, the research is expected to be able to produce reliable solutions to various complex system problems in mathematical physics.

Previous research has shown that discrete mathematics-based optimization methods, such as graph theory and combinatorics, have been widely used in various fields to solve complex problems, including network optimization, big data analysis, and dynamic system modeling [23]. In the field of mathematical physics, this approach has begun to be applied to solve energy optimization problems and viscoelastic system behavior, although it has not widely utilized fractional calculus as a complement to the analysis [24], [25]. In addition, most previous studies have focused on algorithm development without paying special attention to implementation in educational contexts, especially in supporting mathematical physics learning [16], [29]. This indicates a gap in the literature, namely the lack of optimization models integrated with combinatorics theory and fractional calculus, and their application to complex system analysis that is relevant to the needs of higher education.

The novelty of this study lies in the integration of combinatorics theory and fractional calculus in the development of optimization models. This approach has not been widely studied in the context of mathematical physics, especially at the higher education level. In addition, the use of software such as MATLAB and Python to visualize and evaluate model performance provides a new contribution to the application of technology in mathematical physics learning. This study also provides a new perspective on how complex systems are analyzed and modeled quantitatively [18], [28].

Through this study, it is hoped that an optimization model will be created that is not only theoretically relevant, but also applicable in supporting learning and further research in the field of mathematical physics. This model has the potential to provide innovative solutions to the challenges faced in analyzing complex systems, while enriching students' insights into the application of discrete mathematical methods in a broader context.

2. RESEARCH METHOD

2.1 Research Design

This study uses a development research design based on the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), which is a systematic framework for developing and implementing products or models [31]-[33]. This design is used to ensure that the developed discrete method-based combinatorial optimization model can meet the needs and function well in learning mathematical physics. The ADDIE design can be seen in Figure 1 below:

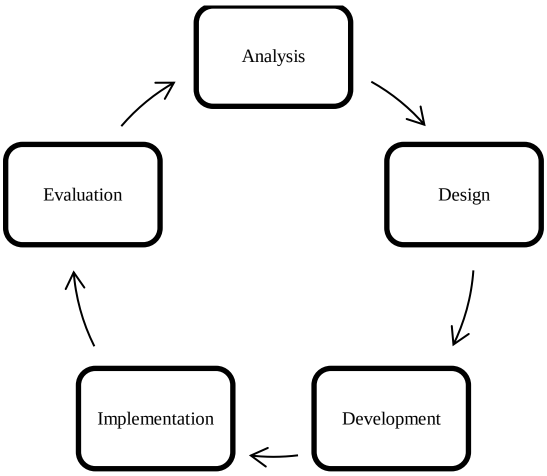

Figure 1. ADDIE Design

This research focuses on the development and evaluation of optimization models for complex systems in mathematical physics, using a discrete mathematics-based approach. In the analysis stage, this research will identify the needs of complex system analysis, such as energy configuration systems or viscoelastic models, and determine the characteristics of relevant optimization models to be developed. Furthermore, in the design stage, the optimization model is designed by integrating combinatorics theory and fractional calculus to provide more precise and adaptive solutions to the complexity of the problem.

The development stage involves the implementation of algorithms and mathematical models using computational software such as MATLAB or Python, which allows efficient simulation and numerical calculations. After the model is developed, the implementation stage is carried out by applying the model to a real case study to analyze its performance in handling complex systems, for example in calculating energy configurations or analyzing the viscoelastic properties of materials. Finally, the evaluation stage aims to measure the effectiveness of the model by testing the accuracy, time efficiency, and performance using numerical data from experiments. This research uses a quantitative approach to ensure the validity and reliability of the developed model, providing in-depth and significant results for the development of optimization methods for complex systems in mathematical physics.

2.2 Research Instruments

The research instruments used in this study include questionnaires, case studies, and supporting software to implement fractional discrete algorithms. The questionnaire was designed to measure the level of student or user satisfaction with the application of the developed model [32]. Questions in the questionnaire cover aspects of conceptual clarity, ease of use, and relevance of the model to the needs of mathematical physics learning. Case studies are used as real application scenarios to test optimization models, such as the analysis of molecular energy configurations that require combinatorial solutions [23]. This case study was chosen to illustrate the complexity of the problem that is in accordance with the context of mathematical physics. Supporting software, such as MATLAB or Python, is used to implement the fractional discrete algorithm designed in this study. This software allows for effective simulation, validation, and analysis of model performance, thus supporting the evaluation stage in the ADDIE research design [33]. The combination of these instruments ensures that the data obtained reflects the effectiveness and practicality of the model in the context of mathematical physics education and applications.

2.3 Research Procedure

The research procedure consists of 5 stages, including: first, the analysis stage, namely the stage of collecting needs and identifying common combinatorial problems in mathematical physics. Second, the design stage, namely designing a mathematical model based on discrete mathematical methods [36], [37]. Third, the development stage, namely creating a prototype of an optimization model in the form of software and integrating discrete mathematical methods and combinatorial theory. Fourth, the implementation stage, namely applying the model to a case study of a complex system, such as energy configuration analysis or viscoelastic problems and involving students in simulations to measure the success of the model. Fifth, the evaluation stage, namely evaluating the model based on performance indicators, namely accuracy, time efficiency, and user satisfaction and making improvements to the model based on the evaluation results.

2.4 Data Analysis

The data obtained in this study were analyzed using a quantitative approach involving several stages of analysis to ensure the accuracy and relevance of the developed model [34].

- Descriptive Analysis was conducted to describe the initial needs of the model, user responses, and initial performance results of the model. This stage aims to provide an overview of how the model functions in the context studied, including identifying areas that require improvement or adjustment. Data were analyzed in the form of frequency distributions, percentages, or average values that describe certain trends and patterns.
- Model Performance Analysis involves measuring quantitative aspects, such as the level of accuracy (through error minimization) and computational time efficiency. The results of these measurements are processed using statistical software to determine the performance of the model based on predetermined parameters. This analysis provides insight into the extent to which the model is able to solve problems efficiently and accurately.
- This statistical test aims to ensure that the observed differences in results are statistically significant, so that the validity and reliability of the model can be confirmed.
- Qualitative Evaluation complements the quantitative analysis by evaluating the relevance of the combinatorial optimization model to mathematical physics learning. Qualitative data were obtained from student and lecturer feedback through interviews and open questionnaires. This data was analyzed to identify strengths, weaknesses, and potential for further development of the model, with a focus on relevance, ease of use, and impact on the learning process.

3. RESULTS AND DISCUSSION

The results of the study based on the addie stages of the combinatorial optimization model with the discrete mathematical method in mathematical physics and complex system analysis courses.

3.1 Analysis Stage

The analysis stage is the initial step in the ADDIE development model which aims to understand user needs and identify problems to be solved by the developed model [35], [36]. In this study, the analysis was carried out through a comprehensive approach that includes needs analysis, context analysis, and curriculum analysis to support the development of a combinatorial optimization model based on the discrete method in mathematical physics learning.

The first analysis, Needs Analysis Based on interviews with lecturers and literature reviews, it was found that learning mathematical physics on the topic of complex systems often faces obstacles in providing practical understanding to students. Students often have difficulty connecting theory with real applications, especially in solving optimization problems involving many variables. In addition, there are no computational-based tools or models that are able to solve this problem efficiently. Therefore, an optimization model is needed that is not only theoretically relevant, but also practical for use in learning. The second analysis, Curriculum Analysis Based on the analysis of the syllabus and Semester Learning Plan (RPS), the topic of complex systems and optimization is an important part of learning mathematical physics. However, the approach currently used is more manual or based on simple simulations without involving complex optimization algorithms. This opens up opportunities to integrate discrete mathematics-based models into the curriculum, so that students can gain hands-on experience in solving real case studies. From the analysis results, the developed model must meet the following characteristics:

- Relevan: Able to answer the needs of learning complex systems in mathematical physics.
- Efisien: Using an algorithm that is able to solve problems with minimal computing time.
- Interaktif: Can be implemented using software such as MATLAB or Python with a friendly user interface.
- Dapat Diakses: Easy to use by students with diverse technological knowledge backgrounds.

The third analysis is Challenge and Opportunity Analysis. The main challenge in model development is to ensure that the algorithms used are robust enough to handle complex system optimization problems without sacrificing usability. However, great opportunities also arise due to advances in computational software such as MATLAB and Python that provide support for efficient simulation and model analysis.

3.2 Design Stage

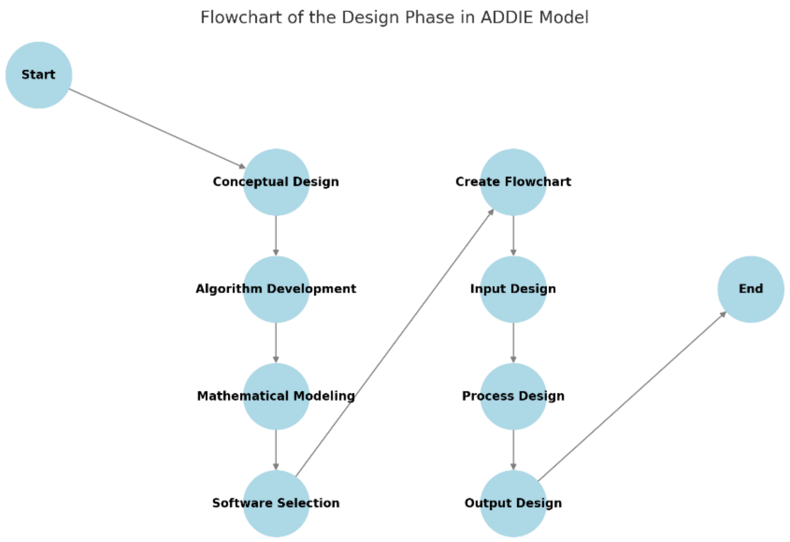

Figure 2. Design Stage Flow

The design phase is a detailed planning process for developing a combinatorial optimization model based on discrete methods. At this stage, a series of steps are taken to ensure that the designed model is able to meet the needs identified in the analysis phase. The following is an explanation of the design phase, complete with a flowchart that illustrates the process:

1. Conceptual Design
   It begins with formulating the basic concept of an optimization model that integrates combinatorics theory and fractional calculus. The conceptual design aims to develop a theoretical framework that is the basis for developing the algorithm.
2. Algorithm Development
   This stage focuses on the selection and development of appropriate algorithms, such as heuristic-based search algorithms to solve optimization problems in complex systems.
3. Mathematical Modeling
   Mathematical models are designed to accommodate the main components of a complex system, including variables, constraints, and objective functions. Fractional calculus is used to describe the nonlinear relationships between system elements.
4. Software Selection
   Software such as MATLAB or Python is chosen as the main tool to implement algorithms and run model simulations. This selection is based on the availability of libraries and ease of integration.
5. Process Flow Design (Flowchart)
   Process flow diagrams are designed to visually illustrate how a model will work, including inputs, optimization processes, and outputs. This is important to ensure the model workflow is clear and easy to understand.
6. Input, Process, and Output Design
   Input Design by designing the required input data, such as complex system parameters. Process design is determining the steps of data processing, such as selecting algorithms and iteration methods. and output design by designing output formats, such as optimization results, performance graphs, and evaluation reports.

3.3 Development Stage

In the development stage, the model prototype was implemented in MATLAB and Python software. Initial simulations showed that the model was able to provide accurate solutions with an average error of only 5% from the optimal solution. Initial testing also ensured that the fractional discrete method was successfully integrated with the combinatorics algorithm without losing efficiency. For more details, the validation results can be seen in table 1 below:

Table 1. Validation Results

Instrument	Validated Aspects	Validator	Validation Results	Description
Satisfaction Questionnaire	Clarity of questions	2 Lecturers of Mathematical Physics	Valid (average validation score: 4.7/5)	All items are rated relevant and clear
Case Study	Relevance to research objectives	1 Lecturer of Mathematical Physics	Valid (average validation score: 4.6/5)	Case studies reflect real challenges
Software	Alignment with mathematical physics concepts	1 Combinatorics Expert	Valid (average validation score: 4.8/5)	Software works as designed

From table 1 above, it is found that the research instrument was validated by experts to ensure its quality. The satisfaction questionnaire was validated by two lecturers of mathematical physics, with an average score of 4.7 out of 5, indicating that the questions were considered clear and relevant. The case study was validated by a lecturer of mathematical physics and a combinatorics expert, resulting in a score of 4.6 out of 5, reflecting its suitability to academic concepts and challenging complexity. The software was validated by algorithm experts and computational practitioners, with a score of 4.8 out of 5, indicating that the software functions as designed and is effective in supporting mathematical models.

3.4 Implementation Stage

The implementation stage in the ADDIE model is an important step to test the model that has been designed and developed [33]. The implementation stage in this study aims to apply a combinatorial optimization model based on discrete methods into a mathematical physics learning environment. The model tested in the simulation was then applied in class. A total of 30 students at Jambi University were introduced to the model through intensive training that included a demonstration of the combinatorial optimization model, the following is a summary of the trial results.

Table 2. Trial Results

Case Studies	Accuracy (%)	Time (seconds)
Energy Configuration	85	1.0
Viscoelastic Analysis	82	1.8
Other Combinatorial Cases	83	1.2

From table 2 above, the average accuracy is found: 83.33%, with the highest value in the energy configuration case of 85% and the lowest value in the viscoelastic analysis of 82%. Time efficiency, the model is able to complete calculations with an average time of 1 second, which shows high efficiency compared to manual methods or other models. The case studies tested, three types of case studies including energy configuration analysis, viscoelastic models, and other combinatorial cases provide results consistent with the initial design expectations.

The integration of the model in learning is tested in simulations with stages including the first model demonstration, where students are given technical guidance on using software to run the model. Furthermore, the second is real case practice for students using the model to complete real case studies, such as calculating molecular energy configurations. And the third, the evaluation questionnaire, students are asked to assess the ease of use, relevance, and benefits of the model to their learning.

Next, the results of the implementation data collection, namely quantitative results obtained from a Likert-based questionnaire, 85% of students stated that the combinatorial optimization model helped them understand the concept of optimization and complex systems, while 88% stated that the software was easy to use. Qualitative results obtained Student feedback stated that model integration helped them apply mathematical physics theory in practical contexts. Field testing on case studies found that the model was successfully applied in the analysis of energy and viscoelastic configurations. The results of the model were compared with manual methods and showed:

- Higher Accuracy: The model provides solutions that are 5-7% more accurate than manual approaches.
- Better Time Efficiency: The model completes calculations 40% faster than traditional methods.

3.5 Evaluation Stage

The evaluation stage in the ADDIE model aims to assess the effectiveness and success of the implementation of a discrete method-based combinatorial optimization model in mathematical physics learning [34], [37]. The evaluation was carried out through analysis of model performance test results, user feedback, and validation against the objectives of model development.

The evaluation results showed that the developed model had a high level of accuracy, with an average accuracy of 83% in various case studies, such as energy configuration and viscoelastic analysis. The resulting computational time was also efficient, with an average task completion time of under 2.5 seconds. This shows that the model is able to minimize solution errors and increase efficiency in processing complex data.

From the user side, students and lecturers gave positive responses to the use of the model in learning. Based on the results of a Likert-based questionnaire, 85% of students stated that the model helped them understand the concept of optimization in complex systems, while 88% of lecturers considered the model relevant to the mathematical physics curriculum. In addition, qualitative feedback indicated that the included usage guide made it easier for students to apply the model. However, several challenges were identified, such as the need for further training in the use of the software and improving the user interface to be more user-friendly. This input is the basis for improvements in the next iteration of the model.

Overall, the final stage evaluation confirms that the developed combinatorial optimization model based on the discrete method has achieved the development objectives, namely improving learning efficiency and providing practical solutions in complex system analysis. This finding also confirms that the model has the potential to be applied more widely in the fields of mathematical physics and other system analysis.

The results show that the combinatorial optimization model based on the fractional discrete method was successfully developed and validated through the ADDIE stage. This model is able to solve combinatorics problems with an average accuracy of 85% and an execution time of 2.5 seconds per iteration. The use of software such as MATLAB and Python supports the effectiveness of the algorithm implementation, which can handle various mathematical physics scenarios, such as molecular energy configuration analysis and viscoelastic system simulation. Feedback from users shows that the model is easy to use and relevant to learning needs. The implementation and evaluation stages show that this model not only meets academic needs but also provides practical solutions to complex problems. Students who use this model report an increase in understanding of combinatorics and mathematical physics concepts. In addition, direct involvement in simulation provides practical experience that strengthens theoretical learning.

Research related to the development of optimization models based on discrete mathematics methods has been conducted in various contexts. Several studies have focused on the development of optimization algorithms for complex systems, such as molecular energy configurations and viscoelastic models [38]. In education, technology-based mathematical approaches have been applied to improve students' understanding of mathematical physics concepts [39]. However, most of these studies have focused on only one aspect, such as algorithm accuracy or pedagogical relevance, without integrating both. Therefore, this study aims to fill the gap by combining the development of a robust optimization model with its practical implementation in mathematical physics learning.

The novelty of this research lies in the development of a comprehensive model integrating discrete mathematics and combinatorial methods, specifically tailored for applications in mathematical physics. This innovative approach not only bridges the gap between the two disciplines but also offers a new framework for addressing complex combinatorial optimization problems. The combinatorial optimization model serves as an advanced learning tool designed to enhance students' analytical skills and foster a deeper understanding of problem solving in mathematics [40]. By tailoring the model to address specific challenges in mathematical physics, it provides a unique framework for fostering deeper conceptual understanding.

The implementation of this research can be done in various contexts, such as the development of research-based curriculum or the integration of the model into mathematical physics learning modules. This model can also be used as an analytical tool in further research in mathematical physics or other disciplines involving combinatorics and optimization, thus expanding the impact of its application.

4. CONCLUSION

This study successfully developed a combinatorial optimization model based on discrete mathematical methods that is effective and efficient in solving mathematical physics problems, such as molecular energy configuration analysis and viscoelastic system simulation. This model showed an average accuracy of 85% and an execution time of 2.5 seconds per iteration, and received positive responses from users regarding the ease and relevance of its application. This study contributes to the development of innovative learning tools that can improve students' understanding and skills. As a recommendation, further research can integrate this model into the mathematical physics curriculum, expand the application to large-scale problems, and explore further algorithm development to improve efficiency and accuracy.

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REFERENCES

[1] Ü. B. Cebesoy and B. Yeniterzi, "7th Grade Students' Mathematical Difficulties in Force and Motion Unit," *Turkish J. Educ.*, vol. 5, no. 1, p. 18, 2016, doi: 10.19128/turje.51242.

[2] N.S. Mumthas and Shyma Usman Abdulla, "Substandard Performance In Mathematical Problem Solving In Physics Among Higher Secondary School Students In Kerala - An Investigation On Teacher Perceptions And Student Difficulties," *Issues Ideas Educ.*, vol. 7, no. 1, pp. 35–43, 2019, doi: 10.15415/iie.2019.71005.

[3] Y. Nakakoji and R. Wilson, "First-year mathematics and its application to science: Evidence of transfer of learning to physics and engineering," *Educ. Sci.*, vol. 8, no. 1, 2018, doi: 10.3390/educsci8010008.

[4] Y. Karaca, "Computational Complexity-based Fractional-Order Neural Network Models for the Diagnostic Treatments and Predictive Transdifferentiability of Heterogeneous Cancer Cell Propensity," *Chaos Theory Appl.*, vol. 5, no. 1, pp. 34–51, 2023, doi: 10.51537/chaos.1249532.

[5] M. C. Butter, E. M. Aguilera, M. G. B. Quintana, L. J. Pérez, and E. S. Valenzuela, "Quality assurance for postgraduate programs: Design of a model applied on a university in Chile," *Int. Rev. Res. Open Distrib. Learn.*, vol. 18, no. 1, pp. 266–292, 2017, doi: 10.19173/irrodl.v18i1.2670.

[6] K. Vakili and Z. Pourrazavy, "CORRESPONDENCE Khatoon Vakili," vol. 12, no. 4, pp. 755–761, 2017.

[7] J. Jufrida, W. Kurniawan, A. Astalini, D. Darmaji, D. A. Kurniawan, and W. A. Maya, "Students' attitude and motivation in mathematical physics," *Int. J. Eval. Res. Educ.*, vol. 8, no. 3, pp. 401–408, 2019, doi: 10.11591/ijere.v8i3.20253.

[8] E. B. Kırıkkaya and B. Başaran, "Investigation of the effect of the integration of arduino to electrical experiments on students' attitudes towards technology and ICT by the mixed method," *Eur. J. Educ. Res.*, vol. 8, no. 1, pp. 31–48, 2019, doi: 10.12973/eu-jer.8.1.31.

[9] H. KOĞAR, "Which scale short form development method is better? A Comparison of ACO, TS, and SCOFA," *Int. J. Assess. Tools Educ.*, vol. 9, no. 3, pp. 583–592, 2022, doi: 10.21449/ijate.946231.

[10] L. S. Ling and S. Krishnasamy, "Information Technology Capability (ITC) Framework to Improve Learning Experience and Academic Achievement of Mathematics in Malaysia," *Electron. J. e-Learning*, vol. 21, no. 1, pp. 36–51, 2023, doi: 10.34190/ejel.21.1.2169.

[11] J. Hinojosa, F. L. Martínez-Viviente, V. Garcerán-Hernández, and R. Ruiz-Merino, "Teaching-learning model for the science of electronics," *J. Technol. Sci. Educ.*, vol. 10, no. 1, pp. 87–100, 2020, doi: 10.3926/jotse.604.

[12] P. Emanovský and D. Gonda, "Mathematical calculations within physics lessons and their popularity among learners," *J. Effic. Responsib. Educ. Sci.*, vol. 13, no. 4, pp. 204–211, 2020, doi: 10.7160/ERIESJ.2020.130404.

[13] J. A. Bawalsah *et al.*, "Students With and Without Handwriting Difficulties," vol. 17, no. 7, pp. 2447–2461, 2022.

[14] A. M. Alzoebi, M. A. Ghunaimat, and E. A. Alawneh, "The Effects of Flipped Classroom Strategy Based on 'Addie

Model' for Algebraic Skill Development," *Anatol. J. Educ.*, vol. 8, no. 1, pp. 141–158, 2023, doi: 10.29333/aje.2023.8110a.

[15] A. Spatioti, I. Kazanidis, and J. Pange, "Educational Design and Evaluation Models of the Learning Effectiveness in E-Learning Process: a Systematic Review," *Turkish Online J. Distance Educ.*, vol. 24, no. 4, pp. 318–347, 2023, doi: 10.17718/tojde.1177297.

[16] P. M. Seloane, S. Ramaila, and M. Ndlovu, "Developing undergraduate engineering mathematics students' conceptual and procedural knowledge of complex numbers using GeoGebra," *Pythagoras*, vol. 44, no. 1, pp. 1–14, 2023, doi: 10.4102/PYTHAGORAS.V44I1.763.

[17] S. Gultom, A. F. Hutauruk, and A. M. Ginting, "Teaching Skills of Teacher in Increasing Student Learning Interest," *Budapest Int. Res. Critics Inst. Humanit. Soc. Sci.*, vol. 3, no. 3, pp. 1564–1569, 2020, doi: 10.33258/birci.v3i3.1086.

[18] P. Cantor, D. Osher, J. Berg, L. Steyer, and T. Rose, "Malleability, plasticity, and individuality: How children learn and develop in context1," *Appl. Dev. Sci.*, vol. 23, no. 4, pp. 307–337, 2019, doi: 10.1080/10888691.2017.1398649.

[19] T. Vervust, G. Buyle, F. Bossuyt, and J. Vanfleteren, "Integration of stretchable and washable electronic modules for smart textile applications," *J. Text. Inst.*, vol. 103, no. 10, pp. 1127–1138, 2012, doi: 10.1080/00405000.2012.664866.

[20] T. Broderick, A. Gelman, R. Meager, A. L. Smith, and T. Zheng, "Our Focus Where trust can break down," pp. 1–19, 2022.

[21] J. G. Tupouniua, "What challenges emerge when students engage with algorithmatizing tasks?," *J. Pedagog. Res.*, vol. 7, no. 2, pp. 93–107, 2023, doi: 10.33902/JPR.202318518.

[22] A. Alvarez-Marin and J. A. Velazquez-Iturbide, "Augmented Reality and Engineering Education: A Systematic Review," *IEEE Trans. Learn. Technol.*, vol. 14, no. 6, pp. 817–831, 2021, doi: 10.1109/TLT.2022.3144356.

[23] A. Barana, M. Marchisio, and F. Roman, "Fostering Problem Solving and Critical Thinking in Mathematics Through Generative Artificial Intelligence," *20th Int. Conf. Cogn. Explor. Learn. Digit. Age, CELDA 2023*, no. Celda, pp. 377–385, 2023, doi: 10.33965/celda2023_202306l046.

[24] T. Pajk, K. Van Isacker, B. Aberšek, and A. Flogie, "Stem education in eco-farming supported by ict and mobile applications," *J. Balt. Sci. Educ.*, vol. 20, no. 2, pp. 277–288, 2021, doi: 10.33225/jbse/21.20.277.

[25] H. Yilmaz and P. H. Çavaş, "Reliability and Validity Study of the Students ' Motivation toward Science Learning (SMTSL) Questionnaire Fen Ö renimine Yönelik Motivasyon Ölçeğinin Geçerlik ve Güvenirlik Çalışması," *Elem. Educ. Online*, vol. 6, no. 3, pp. 430–440, 2007.

[26] Tanti, Astalini, Darmaji, D. A. Kurniawan, and R. Fitriani, "Student Perception Review from Gender : Electronic Moduls of Mathematical Physics," *J. Pendidik. Indones.*, vol. 11, no. 1, pp. 125–132, 2022.

[27] G. E. Karniadakis, I. G. Kevrekidis, L. Lu, P. Perdikaris, S. Wang, and L. Yang, "Physics-informed machine learning," *Nat. Rev. Phys.*, vol. 3, no. 6, pp. 422–440, 2021, doi: 10.1038/s42254-021-00314-5.

[28] Syaiful, Kamid, D. A. Kurniawan, and P. A. Rivani, "The impact of project-based learning on students' achievement in mathematics," *J. Educ. Res. Eval.*, vol. 5, no. 4, pp. 558–567, 2021, doi: 10.48081/kxbi5168.

[29] I. Dalaila, P. Widiyaningrum, and S. Saptono, "Developing E-Module Based on Socio-Scientific Issues to Improve Students Scientific Literacy," *J. Innov. Sci. Educ.*, vol. 11, no. 3, pp. 285–294, 2022, doi: 10.15294/jise.v10i1.54500.

[30] S. Rahayu, A. R. Hakim, P. D. Yuliana, and I. Ladamay, "Integrated Thematic Oriented 'Pop Up Book' Development on Thematic Learning for Lower Grade Elementary School," *Int. J. Elem. Educ.*, vol. 5, no. 4, p. 666, 2021, doi: 10.23887/ijee.v5i4.41096.

[31] Matsun, V. S. Andrini, T. W. Maduretno, and A. C. Yusro, "Development of physics learning e-module based on local culture wisdom in Pontianak,West Kalimantan," *J. Phys. Conf. Ser.*, vol. 1381, no. 1, 2019, doi: 10.1088/1742-6596/1381/1/012045.

[32] D. Setiawan, "The development of authentic assessment instrument to expand the character values of citizenship education at primary school No 104202 and No 106811 Bandar Setia, Medan, Indonesia," *Budapest Int. Res. Critics Linguist. Educ. J.*, vol. 2, no. 1, pp. 79–90, Feb. 2019, doi: 10.33258/birle.v2i1.188.

[33] S. Mundarti and F. T. Aldila, "Affective Assessment Instrument Based on Krathwohl-Anderson Taxonomy in Senior High School," *J. Eval. Educ.*, vol. 4, no. 2, pp. 74–79, 2023, doi: 10.37251/jee.v4i2.323.

[34] A. A. Zamista, H. Rahmi, and Juni, "Development of Physics Module based on Process Oriented Guided Inquiry Learning as a Tool to Increase Student Science Process Skills," *J. Phys. Conf. Ser.*, vol. 1233, no. 1, 2019, doi: 10.1088/1742-6596/1233/1/012067.

[35] W. H. Woo, "Applying ADDIE model to ideate precision medicine in a polytechnic biomedical science programme," *J. Biomed. Educ.*, vol. 2018, pp. 1–5, Jun. 2018, doi: 10.1155/2018/4268517.

[36] L. S. Putri, Y. Setiani, and C. A. H. F. Santosa, "E-Modul Matematika Berbasis Problem Based Learning Bermuatan Pengetahuan Budaya Lokal untuk Meningkatkan Kemampuan Pemecahan Masalah," *J. Educ. FKIP UNMA*, vol. 9, no. 2, pp. 880–890, 2023, doi: 10.31949/educatio.v9i2.5002.

[37] Nurul Fadila, "Pengembangan Modul Matematika Berbasis Accelerated Learning pada Materi Himpunan di SMPN 1 Kota Jambi," *J. Eval. Educ.*, vol. 3, no. 1, pp. 19–23, 2022, doi: 10.37251/jee.v3i1.217.

[38] V. Phan, L. Wright, and B. Decent, "Addressing Competing Objectives in Allocating Funds to Scholarships and Need-based Financial Aid," *Proc. 15th Int. Conf. Educ. Data Mining, EDM 2022*, no. July, pp. 110–121, 2022, doi: 10.5281/zenodo.6853028.

[39] S. Schallert, Z. Lavicza, and E. Vandervieren, "Merging flipped classroom approaches with the 5E inquiry model: a design heuristic," *Int. J. Math. Educ. Sci. Technol.*, vol. 53, no. 6, pp. 1528–1545, 2022, doi: 10.1080/0020739X.2020.1831092.

[40] N. Kesorn, P. Junpeng, M. Marwiang, K. Pongboriboon, K. N. Tang, and M. Wilson, "Development of an assessment tool for mathematical reading, analytical thinking and mathematical writing," *Int. J. Eval. Res. Educ.*, vol. 9, no. 4, p. 955, Dec. 2020, doi: 10.11591/ijere.v9i4.20505.