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Research Article

Development of An Arduino-based Automatic Hybrid Camera Track Mounting for Hybrid Learning Classroom

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Abstract

This study aims to develop a cost-effective Arduino-based automatic hybrid camera track mounting system to support hybrid learning environments in educational institutions with limited budgets. Employing a research and development approach based on the ADDIE model, the system was designed, simulated using SolidWorks, and tested in real classroom settings involving 307 students and 40 lecturers from 13 universities in Indonesia. Validation by expert evaluators resulted in an overall feasibility score of 95%, with key indicators such as efficiency (97%), durability (96%), and precision (97%) rated as highly feasible. Mechanical simulations demonstrated the device's strong structural integrity, with a safety factor exceeding 600, ensuring operational reliability. The developed system provides an affordable, lightweight, and easy-to-assemble solution for hybrid learning implementation, promoting wider access to smart classroom technology and supporting digital transformation in education.

Keywords: arduino; camera track installation; hybrid learning; smart class; educational

1. INTRODUCTION

The development of higher education is guided by the Regulation of the Minister of Education and Culture No. 22 of 2020 on the Strategic Plan 2020–2024, focusing on enhancing learning quality and relevance, improving lecturers and staff, and ensuring quality governance within the Directorate General of Higher Education. Achieving these goals requires active cooperation between the government and universities. Furthermore, Law No. 12 of 2012 Article 35(2) requires universities to develop curricula aligned with national standards, emphasizing intellectual, moral, and skill development. Hence, efforts to improve learning quality and innovate educational systems are crucial [1].

The learning system facilitates interaction between students and lecturers to enhance creative thinking and achieve optimal learning outcomes [2]. To improve link and match between university graduates and the business world or the industrial world with a rapidly changing future, one of which is that in early 2020 the Ministry of Education and Culture enacted a new policy in the field of higher education through the "Independent Learning – Independent Campus (MBKM)" program. The newly implemented MBKM program faces challenges, particularly inadequate facilities and infrastructure to support remote or hybrid learning, limiting students' ability to study without physically attending the campus. This makes it possible to provide more flexible learning alternatives and opportunities for MBKM students. Currently, facilities and infrastructure need to be improved to support the MBKM program related to technology in implementing the hybrid learning program.

Hybrid learning combines online and face-to-face learning to create a flexible and optimal learning environment for students [3]. It allows students to enjoy the advantages of both types of learning and have flexibility and better interaction with teachers and classmates. Learning will be more effective if it can provide a variety of choices and ease of access to students [4]. Currently, the world is entering the era of the industrial revolution 4.0 [5][6]. This era is often referred to as the digital era [7]. It is predicted that hybrid learning will be even more massive in the future [8]. Facilities and infrastructure that support the efficient technology need to be prepared as early as possible [7]. Based on this, there needs to be the right innovation. This innovation can facilitate the implementation of educational goals, support the implementation of MBKM activities in the future, adjust to the

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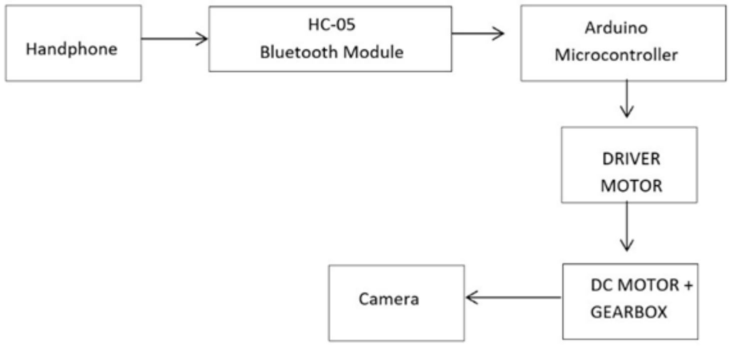

Figure 1. Arduino-based automatic hybrid camera track mounting control tool.

learning needs of current students (Gen Z), support the achievement of Key Performance Indicators (KPIs) of higher education. Hybrid learning that combines traditional learning methods with Information and Communication Technology (ICT) is one of the solutions that can be applied in modern learning in the future [9].

The development of communication technology is the main driver for creating innovative technologies and systems [10]. Today, technology is essential in human life because it helps them do various things, such as work and study [10]. The education sector must continuously adapt to technological advances to support improving the quality of education, especially adjustment in the learning process [11]. One form of innovation that is increasingly being applied is hybrid learning . With the development of technology and information in education, innovative learning models [12]. Hybrid learning allows for more flexible interaction and reaches more students without time of space limitation.In addition, hybrid learning can improve knowledge and skills, especially those related to the use of technology, as well as create conducive learning environment condition [13].

To support the implementation of hybrid learning, adequate rooms and facilities are needed (smart class) [14]. However, creating and developing smart class, especially for implementing hybrid learning, currently requires a costly investment. This certainly not balanced between the need and resources owned and produced only by large universities and those with high enough funds to build them. Therefore, innovative and creative ideas are needed to present alternative products to create and develop smart class using new, more efficient technologies. The researches initiated an innovation product for hybrid learning, developed as Arduino-based automated hybrid camera track mounting product, created to help a cheaper and more efficient hybrid learning process. From this product, it is hoped that it can be implemented in learning, commercialized and utilized by the community in the scope of education and non-education to support the achievement of 8 KPIs higher education to the maximum.

Several previous studies are relevant to related research, hybrid learning as done by previous work related to the use of hybrid learning during the COVID-19 pandemic [15]. Then research related to the implementation of hybrid learning as an alternative learning that provides learning styles and learning preferences that suit the needs of students in the era of the Industrial Revolution 4.0 [16]. From some of the previous studies mentioned above, researchers see opportunities for new research (novelty) to avoid repeating similar research. One of the new things about the products developed in this study is the discovery of new products in learning support technology hybrid which is practical, cheap and more efficient to be applied to smart classroom spaces in hybrid classroom learning [17]. This product can later be commercialized because the market demand for this product is believed to be very large. The product branding produced by this innovation research can later become one of the products that can bring the institution as one of the inventors in the development of learning technology hybrid.

Hybrid learning, which combines online and face -to-face instruction, has become increasingly important in providing flexible and inclusive education that meets the needs of modern students and supports national educational goals. This study addresses this gap by developing a cost-effective Arduino-based camera mounting system, designed to facilitate hybrid learning without compromising functionality or reliability. Therefore, there is a pressing need for innovative and affordable technological solutions that enable wider adoption of hybrid learning. This research aims to develop an Arduino-based automatic hybrid camera track mounting system that can be easily implemented in educational institutions with limited budgets, providing an effective alternative to expensive commercial smart classroom equipment. From the description above, it is necessary to conduct research that aims to conduct development of automatic hybrid camera track installation for learning support hybrid at smart classroom Arduino based".

2. MATERIALS AND METHODS

2.1. Methods

This study uses a Research and Development (R&D) methodology using the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model to create and validate an innovative and cost-effective Arduino-based automatic hybrid camera track mounting system [18]. This study is conducted within the scope of development to ensure that the process remains focused on designing, producing, and testing the prototype. This study integrates qualitative and quantitative approaches (mixed methods) to ensure the validity and reliability of the findings. This study's design of the development model uses ADDIE steps [19]. The data collection techniques used include non-test and test techniques. Data analysis techniques use qualitative and quantitative data analysis techniques [20].

2.2. Research Procedure

2.2.1. Analysis

The analysis phase identified specific needs and gaps in hybrid learning technologies. To assess their needs and preferences, a closed Likert-scale questionnaire was distributed to 307 students and 40 lecturers across 13 universities [21]. Data source is a literature review and analysis of the regulatory framework were conducted to align innovation with the demands of modern education and government policies.

2.2.2. Design

At this stage, the conceptual and technical design of the hybrid camera system was developed. Hardware includes components such as Arduino Nano, HC-05 Bluetooth Receiver, Motor Driver, 30 rpm Motor and Gearbox, power supply, hybrid camera, and jumper cable. The hardware is modeled

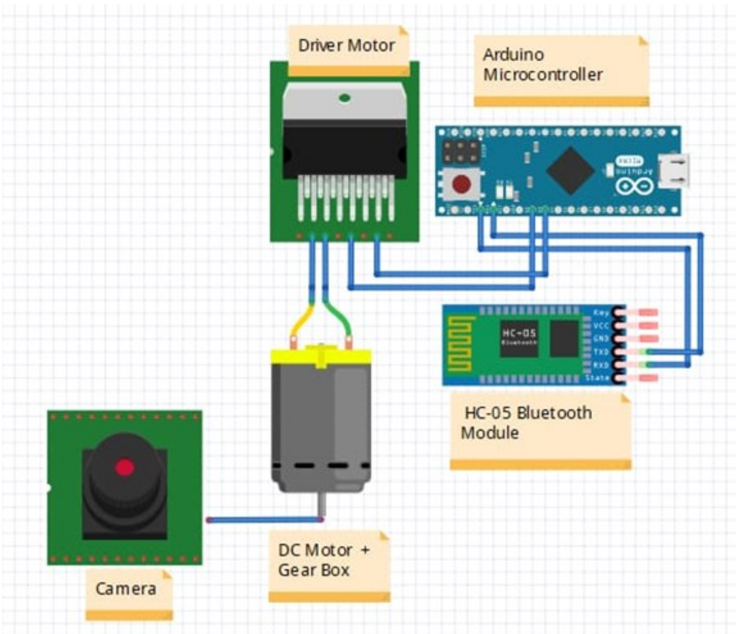

Figure 2. Arduino-based automatic hybrid camera track mounting wiring control scheme.

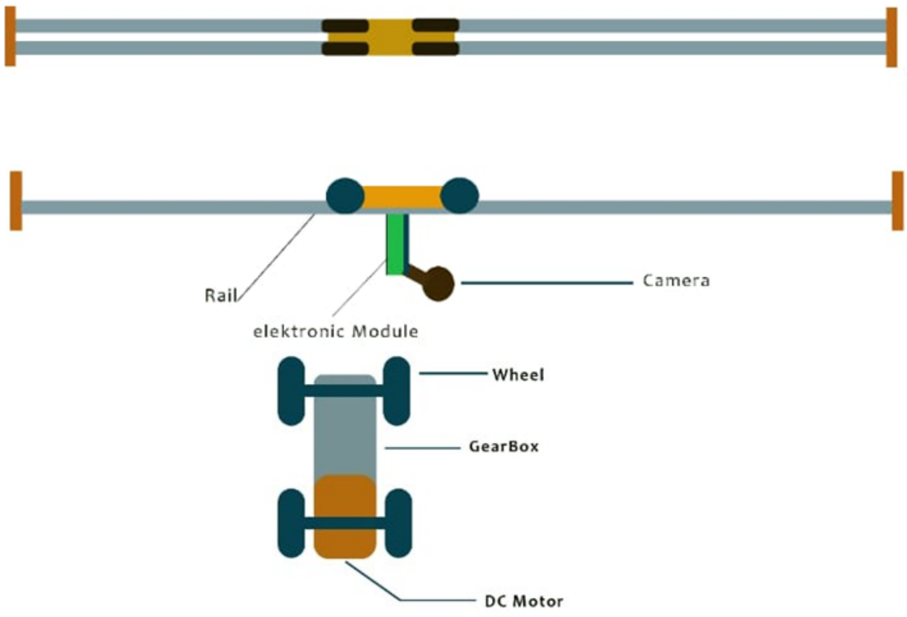

Figure 3. Arduino-based automatic hybrid camera track mounting hardware design.

using SolidWorks to create 3D prototypes and simulate mechanical performance. The software to control the device is programmed using the Arduino IDE, incorporating features for motion tracking and remote control via bluetooth. Validation and testing instruments, including questionnaires for expert validators and simulation tests, are developed. The design stage is the planning of the tool to be developed, at this stage the researcher prepares a design or product design from the results of the analysis that has been carried out previously.

In this study, the design of the automated hybrid camera track mounting system with the hc-05 module and an arduino-based transmitter was carried out from start to finish. This stage has three design from, namely hardware design, software design, and mechanical design. The hardware design block diagram is shown in Figure 1.

Figure 2 shows a schematic of a tool Arduino-based automatic hybrid camera track mounting wiring control scheme developed to support the learning process in a hybrid classroom.

Figure 3 shows a 2D design (hardware design for an Arduino-based automatic hybrid camera track installation) developed to support the learning process in a hybrid classroom.

2.2.3. Development

After design, the next stage is the development of the product designed in this study, namely an Arduino-based automatic hybrid camera track installation tool. The stages in the development of the Arduino-based automatic hybrid camera track installation tool are to prepare electronic components consisting of Arduino Nano, HC-05 Bluetooth Receiver, Motor Driver, 30 rpm Motor and Gearbox, power supply, android, hybrid camera, and jumper cable. The electronic components of the arduino-based automatic hybrid camera track mounting tool device are assembled according to the design. The appliance will be running according to the flowchart once the device is connected to electronic components. The following is a flow chart of the Arduino-based automatic hybrid camera track installation tool.

Data analysis was also carried out at the development stage, namely a feasibility test of an Arduino-based automatic hybrid camera track installation tool using a validation questionnaire based on the calculation of the Likert scale. The feasibility test results are calculated as a percentage of the validation results using the following Equation 1 [22].

$$Validator = \frac{Total\ score}{Maximum\ score} x\ 100\% \quad (1)$$

Once determined, the score percentage is then calculated for the interpretation of the score. The interpretation of the score can be seen in the following Table 1.

3. RESULTS AND DISCUSSIONS

3.1. Analysis

A needs analysis was carried out to determine the need to develop hybrid learning innovations. The research instrument used was a closed questionnaire with four answer choices following the Likert scale guidelines. The sample of this research was 307 students from four universities: Bengkulu University, PGRI Silampari University, Pat Petulai University, and Samudra University, and 40 lecturers from various universities. The results of the analysis of the student needs questionnaire can be seen in Table 2.

Based on Table 2, the results of the distribution of the questionnaire for the analysis of student needs for the development of hybrid learning innovations obtained a percentage of 84.80% and were included in the category of strongly agreeing based on the interpretation of the Liker scale. This shows that students strongly agree with the development of hybrid learning innovations. The results of the analysis of the lecturer needs questionnaire can be seen in Figure 5.

Figure 5, it can be seen that the results of the questionnaire analysis filled out by 40 lecturers from 13 universities showed a positive response with the category of strongly agreeing based on the interpretation of the Likert scale. This shows that the 40 lecturers who filled out the needs questionnaire strongly agreed with the development of hybrid learning innovations. Based on the results of the questionnaire analysis on the need for the development of learning innovations. The content of students and lecturers shows that they strongly agree with the statements contained in the needs analysis questionnaire that describe the need for learning innovation as a support for learning in the digital era.

3.2. Design

This stage formulates goals, designs innovation tools, and develop the instruments. The appropriate goals will be generated from this stage (Fig. S1 – S3).

3.2.1. Object 3D Design

The smart mounting Camera 3D model consists of several main components, such as the camera base, mount, rail, and rail hook. Each element is modeled as a solid object with a level of detail to depict the actual geometry. This model uses the

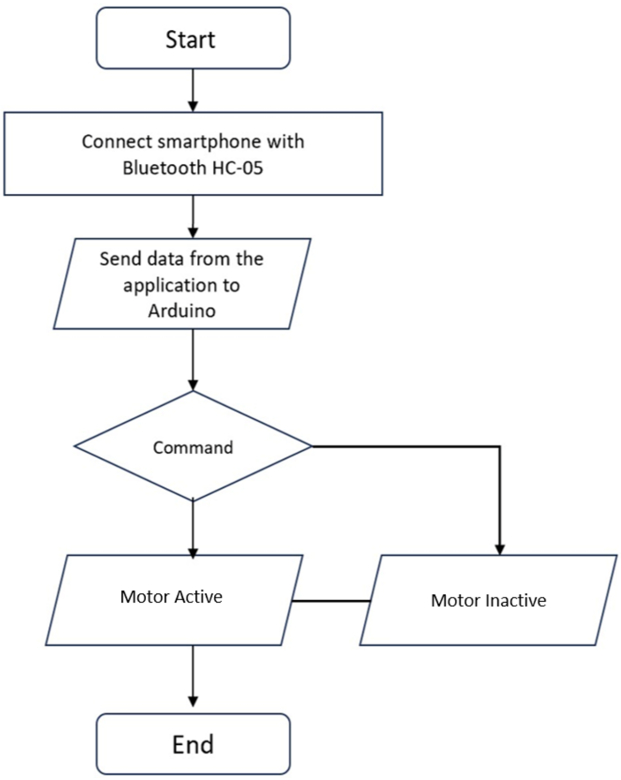

Figure 4. A flow chart of the Arduino-based automatic hybrid camera track installation tool.

Table 1. Likert scale interpretation criteria [23].

Interval	Criterion
75%≤ Score ≤ 100%	Highly worthy
50%≤ Score ≤ 74%	Proper
25%≤ Score ≤ 49%	Not eligible
0%≤ Score ≤ 24%	Very unworthy

default configuration in the simulation to ensure that it is representative. Images of the smart mounting camera can be seen in Fig. S4.

3.3. Development

At this stage, the tool is developed. The results of the developing of the Arduino-based automated hybrid camera track mounting tool can be seen in Fig. S5.

After the tool is completed, a feasibility test is carried out. The feasibility test was carried out by collecting data through a validation questionnaire from several validators. Based on the validation results of the validators consisting of 3 experts, the feasibility results of the Arduino-based automated hybrid camera track mounting were obtained to support hybrid learning. The feasibility test was reviewed from 15 statements developed from 5 assessment indicators, namely the essence of the tool, the durability of the tool, aesthetics, precision value, and safety. The results of the examination of each indicator can be seen in Table S2.

In the efficiency indicator of the tool, the validation results by the expert team were obtained on average at 97% with a very feasible category based on the interpretation of the score. In this aspect, the assessment is measured by the ease of use of the Arduino-based automated hybrid camera track mounting as a hybrid learning support. Based on the results of the validator assessment, the Arduino-based automatic hybrid camera track mounting, as a hybrid learning support is easy to use and assembled by teachers or other users without the need for extensive special training. In the durability indicator of the tool, the validation results showed an average of 96%, which is very feasible category. Based on validator research, the developed tool has weather resistance and is easy to maintain. Based on aesthetic indicators, the validation results show 92% with a very feasible category based on the validator evaluation, where the automated hybrid camera track mounting developed has an attractive shape and the components that make up the device are neatly installed.

In ensuring that the system can support hybrid learning in smart classrooms well, the development of proper installation of automatic hybrid camera tracks requires special attention to technical details and the application of appropriate methods. Therefore, an assessment was carried out on the precision value of the tool and a score of 97% was obtained with a very feasible category. Based on the validation results, the developed tool functions as an automated hybrid camera track mounting that can be used in hybrid learning. In addition, the props are made according to the pre-defined design and the HC-05 module used works well. And based on safety indicators, it scored 92% stating that the developed tool is safe to use, and has a non-hazardous construction. The validation test results conducted by expert validators on the developed teaching aids obtained an overall percentage of 95%, wich is a very feasible category. This shows that the teaching aids developed are suitable for learning support tools. This finding is reinforced by previous research that states that using cameras that rotate 360° can detect objects around and allow for the acquisition of high-resolution images [24].

3.4. Testing Analysis Tools

The smart mounting camera is designed for stable and flexible shooting in diverse environments. Static simulations using *SOLIDWORKS software* assessed it's reliability and safety to evaluate structural performance under load. The main material used in this model is AISI 1020 (Low Carbon Steel), which has isotropic linear elastic properties. Some of the significant material properties include: modulus of elasticity:

E2 x 10^{11} N/m^2; Poisson ratio: 0.29; voltage result: 3.52 x 10^8 N/m^2; and density: 7900 kg/m^3.

3.4.1. Focusing and Loading Reactions

This simulation uses fixed geometry on 12 model surfaces of the model to simulate realistic boundary conditions. A normal load of 1.47 N is applied to a single surface to represent the pressure or force that may occur on the device during its use. The calculated base reaction shows a total reaction force of 1.47 N without moment reaction. The focus on the smart mounting camera can be seen in Fig. S6. Meanwhile, the application of the load on the smart mounting camera can be seen in Fig. S7.

3.4.2. Simulation Results

The simulation results show that the design can safely withstand the load , as shown in the following details: maximum stress (von Mises): 0.5787 MPa, well below the materials' yield stress. The maximum displacement is 0.0071 mm, indicating minimal negligible deformation. The maximum strain is within the limit of the elasticity of the material 1.83 x 10^{-6}. The maximum safety factor is 607.5, indicating the design is very safe against the applied load. Based on the simulation results in Fig. S8 – Fig. S12, the smart mounting camera design is sturdy and can support objects with minimal deformation and tension under material surface. This shows that the design can be used reliably under the anticipated operational conditions.

Smart mounting camera is an innovative device designed to provide stability and flexibility in shooting or video in a variety of environments. To ensure the reliability and safety of the design, static simulations are carried out to evaluate thestructures performance against the loads experienced. This report documents the results of static analyses performed using SOLIDWORKS simulation software.

3.4.3. Tension and Strain

Normal stress (σ) is the intensity of the force acting perpendicular or normal to the cross-section. Since this stress has a vertical direction to the cut surface, this stress is called normal stress. Similarly, it can be described in Equation. 2.

$$\sigma = \lim_{x \to 0} \Delta A = 0 \frac{\Delta F}{\Delta A} \quad (2)$$

So that it becomes Equation 3.

$$\sigma = \frac{F}{A} \quad (3)$$

where F is cross-sectional perpendicular force (N) and A is cross-sectional area (mm^2). While shear stress is the intensity of the force at a point parallel to the cross-section (Equation 4);

$$\tau = V = \lim_{x \to 0} \Delta A = 0 \frac{\Delta V}{\Delta A} \quad (4)$$

where τ is shear stress (N/mm^2), ΔV is cross-sectional parallel force (N), and ΔA is cross-sectional area (mm^2). Strain is defined as the ratio of the increase in rod length to initial length, so that it is expressed by Eq. 5 [25];

$$\varepsilon = \frac{\Delta L}{L} \quad (5)$$

where ε is tension (%), ΔL is increased length (mm), and L is starting length – start (mm).

Strain measures of how much change occurs in the stem [26]. In the elastic region, the magnitude of the tension is directly proportional to the strain. Mathematically, the modulus of elasticity (E) is formulated as Eq. 6.

$$E = \frac{\sigma}{\varepsilon} \quad (6)$$

3.4.4. Maximum Normal Voltage Theory

For the maximum normal voltage, the state of a material is said to be failed if there is a load equal to or greater than the maximum normal voltage (Eq. 7).

$$\sigma_{max} \geq \sigma_{yp} \quad (7)$$

Table 2. Results of student questionnaire distribution.

Number of Students	Number of Scores Obtained	Total Score	Percentage	Group
307	20826	24560	84.80%	Strongly agree

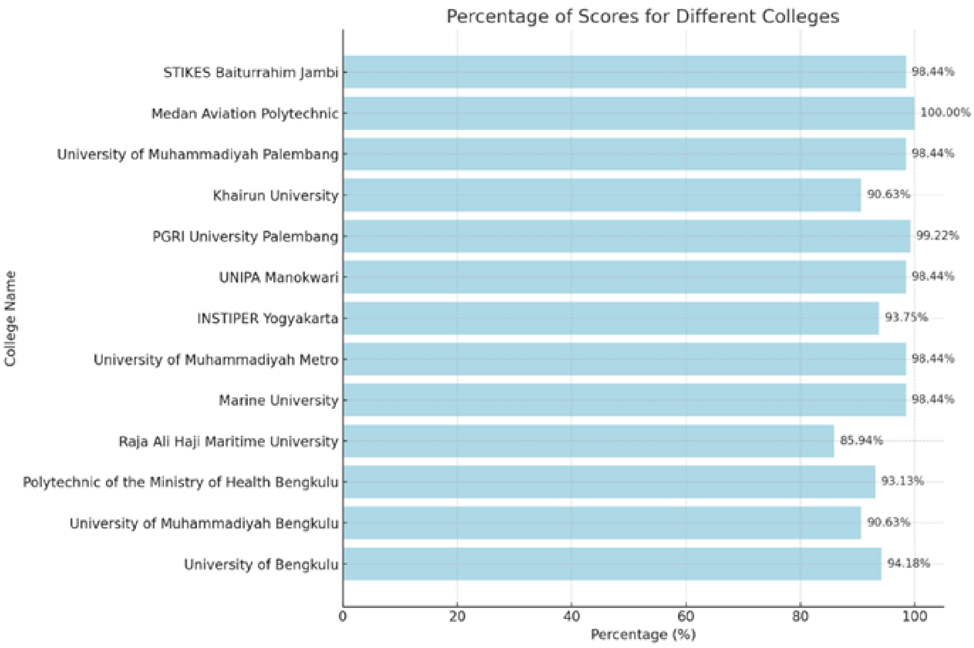

Figure 5. Distribution of percentage scores for participating colleges.

In general, the theory of maximum tension can be shown as follows Eq. 8 and 9;

$$\sigma_{max} = \frac{\sigma_x - \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}{}^2} \quad \textbf{(8)}$$

$$SF = \frac{\sigma_{yp}}{\sigma_{max}} \quad \textbf{(9)}$$

where σ_x is directional voltage x, σ_y is directional voltage y, σ_{yp} is yield point, τ_{xy} is XY direction shear stress, and SF is safety factor. Failure will occur if the maximum normal stress due to the load is greater than the yield point.

3.4.5. Maximum Shear Voltage Theory

The theory of maximum shear stress is often used on ductile materials. The magnitude of the maximum shear stress value is half of the maximum normal stress value. Material failure criteria with loading τ_{max} (Eq. 10).

$$\tau_{max} \geq 0{,}5\ \sigma_{yp} \quad \textbf{(10)}$$

In general, the theory of maximum shear stress is shown in the following Equation 11 and 12.

$$\tau_{max} = \sqrt{\left(\frac{\sigma_x + \sigma_y}{2}\right)^2 + \tau_{xy}{}^2} \quad \textbf{(11)}$$

$$SF = \frac{0{,}5\ \sigma_{yp}}{\tau_{max}} \quad \textbf{(12)}$$

Failure will occur if the maximum normal stress due to the load is greater than the point yield.

3.4.6. Energy Distortion Theory (von Mises)

The von Mises stress criterion was used to evaluate material failure, ensuring the stress experienced by the structure remains within safe limits [27]. Failure criteria on the structure if there is a load with σ (Eq. 13).

$$\sigma' \geq \sigma_{yp} \quad \textbf{(13)}$$

The von Mises voltage equation for a three-dimensional structure is given as Eq. 14.

$$\sigma' = \sqrt{\frac{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}{}^2 + \tau_{yz}{}^2 + \tau_{zx}{}^2)}{2}} \quad \textbf{(14)}$$

where σ_x is directional voltage x, σ_y is directional voltage y, σ_z is voltage in the z direction, τ_{xy} is XY direction shear stress, τ_{yz} is swing voltage in the yz direction, and τ_{zx} is directional shear voltage zx. As for two-dimensional structures, the following Equation 15 and 16.

$$\sigma' = \sqrt{\frac{\sigma_x - \sigma_y{}^2 - \sigma_x \sigma_y + 3\ \tau_{xy}{}^2}{2}} \quad \textbf{(15)}$$

$$SF = \frac{\sigma_{yp}}{\sigma'} \quad \textbf{(16)}$$

3.4.7. Voltage-to-mass Ratio (Voltage-Specific)

The output of the simulation results is the distribution and the amount of stress that occurs on the main landing gear structure. From the distribution and the amount of stress, the strength of the material and whether it is still within the safe limit of the yield criteria are analyszed. The structure of the main landing gear will be analyzed using the failure criterion, namely, von Mises' failure theory. Meanwhile, the stress ratio to mass is the stress that occurs in the main landing gear’s structure divided by the main landing gear’s total mass. When a structure undergoes pressure, indirectly, the structure also change in shape, commonly called deformation. The existing failure theory is adjusted to materials used. The theory of maximum normal stress is more effectively used for brittle materials. As for ductile materials, shear stress and von Mises' theory are more effectively used.

3.4.8. Safety Factor

The value of the safety factor of each construction design on a machine component varies. In ancient times, the value of the safety factor did not consider the detailed factors, so the security factor was quite significant, between 20 to 30. Along with technological advancements, the safety factor in the design must consider almost all factors that can increase the occurrence of failures.Hence, the value of the safety factor is not as significant as it used to be. The safety factor values for some of the machine constructions are shown in Table S3.

3.4.9. Object 3D Description

The smart mounting camera 3D model consists of several main components, such as the camera base, mount, rail, and rail hook. Each element is modeled as a solid object with a level of detail to depict the actual geometry. This model uses the default configuration in the simulation to ensure that it is representative. Images of the smart mounting camera can be seen in Fig. S13.

The main material used in this model is AISI 1020 (Low Carbon Steel), which has isotropic linear elastic properties. Some of the significant material properties include modulus of elasticity of E2 x 10^{11} N/m^2, Poisson ratio of 0.29, voltage result: 3.52 x 10^8 N/m^2, and density of 7900 kg/m^3.

In-class tool testing, as shown in Fig. S14, confirms that the Arduino-based automatic hybrid camera track mounting system has been successfully developed and implemented according to the initial design. The system operates stably, follows movements as instructed, and demonstrates reliability under actual conditions. This testing validates that the design previously simulated using SolidWorks can be effectively applied in a hybrid classroom setting, providing an innovative, cost-effective alternative to existing commercial systems. The implications of this research for hybrid learning are highly significant. With this system, educational institutions now have a more affordable option to implement Smart Classrooms previously only accessible to universities with large budgets. The flexibility of this device allows lecturers and students to interact more effectively without complex technical constraints. The primary contribution of this research is expanding access to hybrid learning, reducing operational costs for education, and supporting digital transformation in academia. Furthermore, this innovation lays the groundwork for future research in IoT-based automated learning systems, fostering a more adaptive and interactive learning ecosystem for the future.

4. CONCLUSIONS

The conclusion of the tool development shows significant success in various aspects. The developed Arduino-based automatic hybrid camera track mounting tool has been proven to function well, offering the advantages of much lower cost and lightweight design compared to similar solutions on the market that tend to be more expensive. The effectiveness and efficiency of the tool are reinforced by the expert validation results, which show an overall feasibility score of 95%, with key indicators such as tool efficiency (97%), durability (96%), and precision (97%) reaching the “very feasible” category. In addition, simulations demonstrated the device's ability to safely withstand operational loads, with a safety factor of 607.5, proving exceptional reliability. The developed tool has reached the prototype stage and is ready for initial commercialization testing. This innovative tool can also provide a better and efficient solution to the hybrid learning implementation problem. The need for hybrid learning innovation is very high, as shown by the positive responses from 307 students (84.8%) and 40 lecturers (95.0%) from 13 universities across Indonesia. Furthermore, developing this tool opens up opportunities for further collaboration, synergy, and partnership with various universities. Lastly, the developing of this tool involves MSMEs, which can encourage cooperation with higher education business units and trigger cooperation with surrounding MSMEs, thus providing tangible economic benefits.

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Author Contributions

The conceptualization and design of the learning technology were carried out by E. R., D. A. D., and R. R.. The methodology was developed by E. R.. Software development was handled by R. R.. The validation process was conducted by E. R., A. S., R. R., D. A. D., and D. R. N.. Formal analysis and investigation were performed by E. R., who also contributed to resource provision and data curation. The original draft was prepared by E. R., with writing, review, and editing carried out by M. S.and H. A. K.. The 2D and 3D visualizations were managed by D. R. N.. Project supervision was provided by R. R., J. F., A. K.and D. A. D.. This study is the outcome of an interdisciplinary collaboration, integrating expertise from Educational Technology, Physics, Online Learning, Artificial Intelligence, Mechanical Engineering, Learning Models, and Instrumentation.

Conflicts of Interest

The authors declare no personal circumstances or interests that may be perceived as influencing the representation or interpretation of the research results reported in this article. Furthermore, there was no involvement of the funding sponsors in the selection of the research project, the design of the study, the collection, analyses, or interpretation of data, the writing of the manuscript, or the decision to publish the results. The authors declare no conflict of interest.

SUPPORTING INFORMATION

Supplementary data associated with this article can be found in the online version at doi: 10.47352/jmans.2774-3047.299

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REFERENCES

[1] S. Rabani, A. Khairat, X. Guilin, and D. Jiao. (2023). "The Role Of Technology In Indonesian Education At Present". *Journal of Computer Science Advancements.* **1** (2): 85-91. 10.55849/jsca.v1i1.403.

[2] K. Børte and S. Lillejord. (2024). "Learning to teach: Aligning pedagogy and technology in a learning design tool". *Teaching and Teacher Education.* **148**. 10.1016/j.tate.2024.104693.

[3] A. Ortega-Arranz, I. Amarasinghe, A. Martínez-Monés, J. I. Asensio-Pérez, Y. Dimitriadis, M. Corrales-Astorgano, and D. Hernández-Leo. (2024). "Collaborative activities in hybrid learning environments: Exploring teacher orchestration load and students' perceptions". *Computers & Education.* **219**. 10.1016/j.compedu.2024.105105.

[4] D. Gudoniene, E. Staneviciene, I. Huet, J. Dickel, D. Dieng, J. Degroote, V. Rocio, R. Butkiene, and D. Casanova. (2025). "Hybrid Teaching and Learning in Higher Education: A Systematic Literature Review". *Sustainability.* **17** (2). 10.3390/su17020756.

[5] M. A. I. Gazi, M. K. Rahman, M. Bin Amin, M. A. Hossain, M. Sultana, A. R. b. S. Senathirajah, and V. Fenyves. (2025). "Dual Aspects of COVID-19 on Facilitating Conditions and Students' Willingness to Continue Online Learning". *Educational Process International Journal.* **15** (1). 10.22521/edupij.2025.15.121.

[6] A. Ebekozien, M. A. Hafez, C. Aigbavboa, M. S. Samsurijan, A. Z. Al-Hasan, and A. N. C. Nwaole. (2024). "Appraising Education 4.0 in Nigeria's Higher Education Institutions: A Case Study of Built Environment Programmes". *Sustainability.* **16** (20). 10.3390/su16208878.

[7] A. Haleem, M. Javaid, M. A. Qadri, and R. Suman. (2022). "Understanding the role of digital technologies in education: A review". *Sustainable Operations and Computers.* **3** : 275-285. 10.1016/j.susoc.2022.05.004.

[8] C. Dede and W. Lidwell. (2023). "Developing a Next-Generation Model for Massive Digital Learning". *Education Sciences.* **13** (8). 10.3390/educsci13080845.

[9] T. A. Ibrahim and J. O. Obinna. (2024). "Strategies for the Effective Implementation of Information and Communication Technology (ICT) in Colleges of Education, Enugu State". *IJOEM Indonesian Journal of E-learning and Multimedia.* **3** (3): 139-145. 10.58723/ijoem.v3i3.302.

[10] M. F. Ahmed, M. H. Kabir, and A. Z. M. T. Islam. (2023). "Impact of Feed Point Position on Patch Antenna's Return Loss and Bandwidth for UWB Applications". *Journal of Multidisciplinary Applied Natural Science.* **4** (1): 30-38. 10.47352/jmans.2774-3047.158.

[11] X. Wu, W. Wider, L. S. Wong, C. K. Chan, and S. S. Maidin. (2023). "Integrating the technology acceptance model on online learning effectiveness of emerging adult learners in Guangzhou, China". *International Journal of Education and Practice.* **11** (2): 129-140. 10.18488/61.v11i2.3282.

[12] K. C. Li, B. T. M. Wong, R. Kwan, H. T. Chan, M. M. F. Wu, and S. K. S. Cheung. (2023). "Evaluation of Hybrid Learning and Teaching Practices: The Perspective of Academics". *Sustainability.* **15** (8). 10.3390/su15086780.

[13] Y. Arfat, M. K. Shahid, R. S. Al-tayyar, K. Mahmood, and A. Alghamdi. (2025). "Building inclusive learning environment through hybrid learning system: Role of

technology and corresponding engagement". *Sustainable Futures.* **10**. 10.1016/j.sftr.2025.100887.

[14] R. Sanchez-Pizani, M. Detyna, S. Dance, and L. Gomez-Agustina. (2022). "Hybrid flexible (HyFlex) seminar delivery – A technical overview of the implementation". *Building and Environment.* **216**. 10.1016/j.buildenv.2022.109001.

[15] Q. Li, Z. Li, and J. Han. (2021). "A hybrid learning pedagogy for surmounting the challenges of the COVID-19 pandemic in the performing arts education". *Education and Information Technologies.* **26** (6): 7635-7655. 10.1007/s10639-021-10612-1.

[16] L. Mekacher. (2022). "Education 4.0: Hybrid Learning and Microlearning in a Smart Environment". *PUPIL: International Journal of Teaching, Education and Learning.* **6** (1): 127-141. 10.20319/pijtel.2022.61.127141.

[17] X. Zhang, Y. Ding, X. Huang, W. Li, L. Long, and S. Ding. (2024). "Smart Classrooms: How Sensors and AI Are Shaping Educational Paradigms". *Sensors (Basel).* **24** (17). 10.3390/s24175487.

[18] A. G. Spatioti, I. Kazanidis, and J. Pange. (2022). "A Comparative Study of the ADDIE Instructional Design Model in Distance Education". *Information.* **13** (9). 10.3390/info13090402.

[19] P. Maharani and D. H. Putri. (2024). "Developing Interactive Learning Media Using Powtoon to Improve Students' Interest and Learning Outcomes in Global Warming Material". *IJOEM Indonesian Journal of E-learning and Multimedia.* **3** (3): 90-99. 10.58723/ijoem.v3i3.288.

[20] H. Theelen, A. van den Beemt, and P. d. Brok. (2019). "Classroom simulations in teacher education to support preservice teachers' interpersonal competence: A systematic literature review". *Computers & Education.* **129** : 14-26. 10.1016/j.compedu.2018.10.015.

[21] R. Luo, J. Li, X. Zhang, D. Tian, and Y. Zhang. (2024). "Effects of applying blended learning based on the ADDIE model in nursing staff training on improving theoretical and practical operational aspects". *Frontiers in Medicine (Lausanne).* **11** : 1413032. 10.3389/fmed.2024.1413032.

[22] H. A. Kartika, A. Purwanto, and E. Risdianto. (2024). "Development of Physics E-Books Assisted by Flipbook and Augmented Reality (AR) to Increase Learning Motivation of High School Students". *Asian Journal of Science Education.* **6** (1): 70-81. 10.24815/ajse.v6i1.36294.

[23] C. W. Gunawan, E. Risdianto, and D. H. Putri. (2022). "Analysis of Need Response to the Development of E - Magazine on Static Fluid Material at Bengkulu City High School". *IJOEM Indonesian Journal of E-learning and Multimedia.* **1** (2): 52-61. 10.58723/ijoem.v1i2.50.

[24] C. Premachandra and M. Tamaki. (2021). "A Hybrid Camera System for High-Resolutionization of Target Objects in Omnidirectional Images". *IEEE Sensors Journal.* **21** (9): 10752-10760. 10.1109/jsen.2021.3059102.

[25] V. Hirschberg, L. Faust, M. Wilhelm, and D. Rodrigue. (2021). "Universal Strain-Life Curve Exponents for Thermoplastics and Elastomers under Tension-Tension and Torsion". *Macromolecular Materials and Engineering.* **306** (8). 10.1002/mame.202100165.

[26] R. E. Freeman, R. Phillips, and R. Sisodia. (2018). "Tensions in Stakeholder Theory". *Business & Society.* **59** (2): 213-231. 10.1177/0007650318773750.

[27] Y. Huang and J. Jiang. (2023). "A Critical Review of von Mises Criterion for Compatible Deformation of Polycrystalline Materials". *Crystals.* **13** (2). 10.3390/cryst13020244.