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Research Article

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Development of Learning Media Based on Arduino Load Cell on Pascal's Law Topic to Improve Students' Learning Outcomes

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ABSTRACT

Observations in several high schools in Bandung City show that students struggle to grasp Pascal's Law due to the absence of concrete visual representations. A preliminary survey involving 72 grade XI students from two schools revealed that only 45% could correctly explain the fundamental concept of Pascal's Law, and around 65% showed a lack of interest in physics, mainly because they found the material too complex. This study aims to develop Arduino Load Cell-based learning media to enhance students' comprehension of Pascal's Law. Using a Research and Development (R&D) approach with the ADDIE model, the study included five phases: analysis, design, development, implementation, and evaluation, with seven grade XII students as participants. The research utilized validation sheets, practicality questionnaires, student feedback forms, and pre-and post-tests. The findings indicated that the learning media exhibited a remarkably high degree of validity and practicality. The students' responses to this media were predominantly favorable, particularly with regard to the benefits it provided. Analysis of learning outcomes showed N-Gain scores ranging from moderate to high, signifying a notable improvement in student understanding. These results underscore the need for interactive learning media to help students better understand Pascal's Law through accurate visualization and hands-on experiments. Therefore, the development of Arduino Load Cell-based media is intended to offer an engaging and interactive learning experience to improve student comprehension of the material.

ABSTRAK

Hasil pengamatan di beberapa SMA di Kota Bandung menunjukkan bahwa siswa kesulitan memahami Hukum Pascal karena tidak adanya representasi visual yang konkret. Survei pendahuluan mengungkapkan bahwa hanya 45% yang dapat menjelaskan konsep dasar Hukum Pascal dengan benar, dan sekitar 65% menunjukkan kurangnya minat pada fisika. Penelitian ini bertujuan untuk mengembangkan media pembelajaran berbasis Arduino Load Cell untuk meningkatkan pemahaman siswa terhadap Hukum Pascal. Dengan menggunakan pendekatan Penelitian dan Pengembangan (R&D) dengan model ADDIE, penelitian ini mencakup lima fase: analisis, desain, pengembangan, implementasi, dan evaluasi, dengan tujuh siswa kelas XII sebagai partisipan. Penelitian ini menggunakan lembar validasi, kuesioner praktikalitas, formulir umpan balik siswa, dan tes pra dan pasca. Temuan menunjukkan bahwa media pembelajaran menunjukkan tingkat validitas dan praktikalitas yang sangat tinggi. Respon siswa terhadap media ini sebagian besar positif, terutama berkenaan dengan manfaat yang diberikannya. Analisis hasil belajar menunjukkan skor N-Gain berkisar antara sedang hingga tinggi, yang menandakan peningkatan pemahaman siswa yang signifikan. Hasil ini menggarisbawahi perlunya media pembelajaran interaktif untuk membantu siswa lebih memahami Hukum Pascal melalui visualisasi yang akurat dan eksperimen langsung. Oleh karena itu, pengembangan media berbasis *Arduino Load Cel*l dimaksudkan untuk menawarkan pengalaman belajar yang menarik dan interaktif guna meningkatkan pemahaman siswa terhadap materi.

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INTRODUCTION

The evolution of educational curricula is essential to meet the demands of a rapidly changing, globalized world. The shift from the 2013 Curriculum to the Merdeka Curriculum was implemented as a response to this need, focusing on developing competencies that better prepare students for future challenges (Nabil et al., 2023). A key component of the Merdeka Curriculum is its emphasis on student-centered learning, which tailors teaching to individual needs, interests, and developmental stages (Kusyanti, 2022; Marlina et al., 2022). This approach requires innovative, interactive teaching methods that foster critical thinking, problem-solving, and creativity.

Physics, as a fundamental science, plays an essential role in helping students understand the laws of nature and apply mathematical models to explain various phenomena (Fidan & Tuncel, 2019). However, to fully engage students in this subject, especially when dealing with abstract concepts, the learning process must include both theoretical instruction and active, hands-on experiences that connect the material to real-life contexts (Marlina et al., 2022). Educators must create engaging and dynamic learning environments that encourage students to express their opinions and relate physics concepts to their everyday experiences (Simbolon & Silalahi, 2023). This calls for a transformation in how physics is taught, moving toward more practical and interactive learning media that help students make deeper connections with the material.

One of the most challenging topics in physics is Pascal's Law, a fundamental principle in fluid mechanics that explains the transmission of pressure in enclosed fluids, critical for understanding hydraulic systems (Matsun et al., 2022). Pascal's Law is important because it connects the theory of liquids with the theory of gases and explains the changes in shape between the two (Maryanti et al., 2022). Despite its importance in linking the theories of liquids and gases, and its practical applications in systems such as brakes and lifts, many students struggle with its abstract nature. A survey of 72 grade XI students in Bandung revealed that only 45% could correctly explain the basic concepts of Pascal's Law, while 65% expressed a lack of interest in the subject, viewing it as complex and difficult to relate to real-world applications. Additionally, 30% of students had misconceptions about the relationships between pressure, volume, and force in fluids. These findings suggest that the current teaching methods are insufficient in helping students understand this key concept.

The root cause of these difficulties can often be traced to the lack of effective visualizations and hands-on experiences in the learning process. Pascal's Law, being a conceptual and abstract topic, requires strong visual support to help students grasp how pressure is transmitted in fluids and how this concept applies to real-world scenarios. Without such visual aids, students struggle to connect theoretical knowledge to practical application, which hampers their learning and deeper understanding (Rzyankina et al., 2024).

Effective learning media are vital for enhancing student engagement and understanding, and they are generally categorized into auditory, visual, and audiovisual types (Khumaedi et al., 2021). Auditory media focus on sound-based learning, visual media rely on images, while audiovisual media combine both sound and visuals to create a richer, more stimulating learning environment. Among these, audiovisual media have proven particularly effective in capturing students' attention and boosting their involvement in the learning process (Rahmawati, 2022). Despite these advantages, the integration of audiovisual media in classrooms presents significant challenges. Implementing such technology requires considerable financial investment for equipment and infrastructure. Additionally, disparities in access to technological tools can create unequal learning opportunities among students, limiting the overall effectiveness of these media. Moreover, excessive dependence on audiovisual media may lead to passive learning, where students become mere recipients of information instead of active participants, potentially impeding the development of critical thinking and independent learning abilities.

However, while audiovisual media have many advantages, their use in the classroom comes with several limitations. The integration of technology-based media requires significant resources, including financial investment,

equipment, and infrastructure. Moreover, not all students have equal access to technological tools, which may lead to disparities in the learning experience. In addition, over-reliance on audiovisual media can result in students becoming passive recipients of information, rather than active participants in the learning process. This can limit the development of independent learning skills and critical thinking (Rahmawati, 2022). Furthermore, the misuse of media—such as using the wrong type, duration, or irrelevant content—can distract students from the core learning objectives.

Compounding this issue is the limited use of technology-based teaching aids. Only 25% of teachers report using such aids regularly, reflecting a broader challenge: insufficient teacher understanding of media variations, media selection, and technical skills necessary to manage these tools effectively. This gap in media utilization contributes significantly to students' struggles in understanding complex physics concepts, particularly in topics like Pascal's Law.

In light of these challenges, the development of Arduino Load Cell-based learning media presents a promising solution. Previous studies have shown that integrating technology in physics education can significantly boost student interest and understanding. For instance, research by Rustiana et al. (2022) indicates that learning aids can enhance student engagement and improve conceptual understanding by up to 45%. Therefore, Arduino Load Cell-based media are designed to offer students a more interactive and hands-on approach to learning Pascal's Law, helping them grasp complex concepts more effectively through accurate visualizations and practical experiments.

The potential of Arduino-based tools in physics education has been highlighted in various studies, showing that such technology can increase student involvement and improve comprehension. For example, Nabil et al. (2023) emphasize the importance of active student participation for achieving optimal learning outcomes. Arduino-based learning media are particularly effective in this regard because they allow students to engage directly with experiments, providing them with a deeper, more interactive understanding of physics principles (Araújo & Saúde, 2025; Chang & Chen, 2022; Lee, 2025). The incorporation of Arduino technology into learning environments also creates more engaging and realistic learning experiences, facilitating the development of critical thinking and problem-solving skills (Fidan & Tuncel, 2019;Fuchs & Corni, 2024).

Many previous studies have developed teaching aids for learning Pascal's Law. For instance, Ardiansyah et al. (2023) created teaching aids aimed at improving students' general science skills related to fluid mechanics. Although these aids showed positive results, including an N-gain of 70.65%, they lacked significant interactivity, with students mostly observing demonstrations rather than actively participating in experiments. Similarly, a study by Rustiana et al. (2022) developed a hydraulic press teaching aid that was highly feasible (85.5% feasibility) for teaching Pascal's Law but still did not allow students to directly engage in the experiments. Research by Pangke et al. (2021) on simple hydraulic machines also demonstrated good outcomes, with an N-gain of 0.90 to 0.92, but the tools remained passive and did not fully involve students in the learning process.

In contrast, this research aims to fill the gap in existing studies by developing Arduino-based teaching aids specifically designed to help students understand Pascal's Law at the junior high school level. Unlike traditional methods that focus on conventional learning media or videos, this approach integrates interactive technology that students can operate themselves. By using Arduino and sensors, the learning media not only offer clearer visualizations of physical principles but also allow students to participate directly in hands-on experiments (Oh, 2025; Papadimitropoulos et al., 2021). This method is considered more effective for improving concept comprehension, as it encourages active engagement and enhances students' ability to visualize and apply theoretical concepts.

Furthermore, this study emphasizes the evaluation of the effectiveness of the developed teaching aid from the students' perspective, providing empirical data on its usefulness and impact on learning outcomes. By incorporating elements of interactivity and student participation, this research aims to create a more engaging and effective learning experience,

addressing a key limitation of previous studies (Muir et al., 2022).

Overall, the development of Arduino Load Cell-based learning media represents a significant innovation in physics education, particularly in teaching Pascal's Law. Arduino is known for its practicality and efficiency, making it an ideal tool for enhancing interactive learning (Fatmaryanti et al., 2024; Pratiwi et al., 2024). The use of Arduino-based tools allows students to actively engage in experiments, providing them with a deeper understanding of the relationship between pressure, volume, and force in fluids. This innovation addresses the traditional challenges of teaching Pascal's Law, where abstract concepts are often difficult for students to grasp without concrete visualizations.

The research question in this study is: "*How does the use of Arduino Load Cell-based learning media affect student learning outcomes in Pascal's Law material?*" Several studies related to the development of learning media, such as those conducted by Ardiansyah et al. (2023) and Pangke et al. (2021), show the potential of teaching aids in improving students' understanding of physics concepts. However, although many studies discuss the development of learning media in the context of Pascal's Law, very few have integrated Arduino technology as a learning medium. Therefore, the existing research gap lies in the lack of studies exploring the use of Arduino Load Cells specifically in learning Pascal's Law. Arduino, being practical in facilitating more accurate and interactive physics experiments, is an ideal tool to enhance students' understanding. This study will fill this gap by developing Arduino Load Cell-based learning media and evaluating its impact on student learning outcomes.

RESEARCH METHOD

This research was conducted in the odd semester of the 2023/2024 academic year at a high school in Bandung City using the Research and Development (R&D) research method and the ADDIE development model. The ADDIE model consists of five stages, namely Analysis, Design, Development, Implementation, and Evaluation (Mutmainnah et al., 2023). The selection of this model is based on its widespread use and systematic steps in instructional development, so it is expected to produce maximum learning (Arikunto, 2015; Sugihartini & Yudiana, 2018). This research was tested on a limited basis on seven grade XII students at a private high school in Bandung City and validated by one physics lecturer and two physics teachers as validators. Five high school physics teachers also tested the practicality of the developed teaching aids.

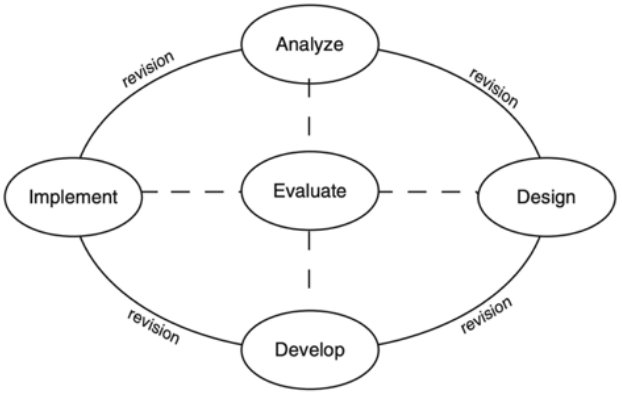

Figure 1. ADDIE Development Research Method (Branch, 2009)

In the analysis stage, the researcher identified several challenges that students face in understanding Pascal's Law, including difficulties with conceptual clarity and the ability to apply theoretical knowledge to real-life situations. These issues highlighted the need for effective teaching aids to bridge the gap between abstract concepts and practical applications. Moving to the design stage, teaching aids were created based on the problems identified, with a focus on addressing these challenges. The design process involved developing interactive components, such as Arduino-based tools, and creating visual aids, including diagrams that clearly illustrate Pascal's Law and its principles. This stage laid the foundation for the development of tools that could actively engage students in the learning process.

In the development stage, technical steps were outlined to ensure the tools were ready for testing. These included refining the design of interactive elements and preparing the teaching media for implementation. The implementation stage followed, where the researcher tested the developed teaching aids with students, observing their responses to assess whether the

tools helped improve understanding. This stage also involved measuring the accuracy and precision of the teaching aids, ensuring they facilitated the intended learning outcomes. Finally, in the evaluation stage, the researcher assessed the effectiveness of the media based on student feedback and performance, identifying any areas for improvement. The evaluation ensured that any deficiencies from the previous stages were addressed to enhance the learning experience.

To evaluate the effectiveness of the developed teaching aids, pretests and posttests were administered to measure students' understanding of Pascal's Law before and after the intervention. The tests assessed various aspects, including the definition, real-life applications, hydraulic systems, fluid pressure concepts, influencing factors, and students' ability to explain pressure differences and equilibrium. This method allowed the researcher to determine how well the teaching aids improved students' comprehension of Pascal's Law.

The instruments used to collect data include validation and practicality questionnaires given to validators and practitioners (lecturers and teachers). In addition, pretests and post-tests are also used to assess the effectiveness of learning media, as well as student response questionnaires to evaluate the efficiency of learning media. The pretest and post-test consist of 10 multiple-choice questions, and the collected data are analyzed using Microsoft Excel and presented in tabular form. The student response questionnaire covers three aspects, namely ease of use, appearance, and benefits, with a total of 10 indicators.

The validation sheet assessment uses a Likert scale, which consists of five response categories: Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree. The use of this Likert scale is often used in research in the fields of social, education, and psychology because it can provide a higher average score for the maximum possible score (Kyriazos & Stalikas, 2018; Simms et al., 2019). The percentage score is calculated using the following formula (Nurhayati et al., 2024):

$$p = \frac{f}{N} x100\% \quad (1)$$

Description:
p = Percentage of score
f = Score obtained
N = Total frequency and maximum score

The data obtained were then categorized based on the level of validity of the learning media, as listed in Table 1.

Tabel 1. Category for Validity of Learning Media (Nurhayati et al., 2024)

No	Scores (%)	Category
1	81 – 100	Very Valid
2	61 – 80	Valid
3	41 – 70	Quite Valid
4	21 – 40	Not Valid
5	0 – 20	Very Not Valid

The expert validation sheets assess the development of Pascal's Law learning media using Arduino Load Cell, focusing on three aspects: Learning Materials, Quality and Appearance of Props, and Benefits of Teaching Aids. These validation criteria are adapted from Nisya et al. (2014).

Table 1. Grid of Validation Sheet for Pascal's Law Learning Media by Experts

No.	Aspect of Validity	Indicators	Number of Item
1	Learning Materials	The material is suitable for the learning objectives of Pascal's Law.	1
		The accuracy of the learning material.	2
		The ability of the material to support students' understanding of concepts.	3
		The ease of the material being understood by students.	4
2	Quality and Appearance of Props	The design of the teaching aids is attractive and supports learning.	5
		The clarity of the visualization of the teaching aids.	6

No.	Aspect of Validity	Indicators	Number of Item
		The quality of the materials and construction of the teaching aids.	7
		The safety of the teaching aids when used by students.	8
3	Benefits of Teaching Aids in Learning	The benefits of teaching aid in improving students' understanding of Pascal's Law.	9
		The ability to learn aids in visualizing physics concepts concretely.	10
		The effectiveness of teaching aids in supporting the interactive learning process.	11
		The ability of teaching aids to improve students' learning motivation.	12
Total			12

In addition, a teacher practicality questionnaire was used to assess the practicality of the developed learning media, calculated using the formula:

$$Practicallity = \frac{Total\ Scores}{Scores\ Maximum} x100\% \qquad (2)$$

The score interpretation criteria for the practicality of Pascal's Law learning media can be seen in Table 3.

Table 2. Category for Practicality of Learning Media (Nisya et al., 2024)

No	Scores (%)	Category
1	$80 < x \leq 100$	Very Practical
2	$60 < x \leq 80$	Practical
3	$40 < x \leq 60$	Quite Practical
4	$20 < x \leq 40$	Less Practical
5	≤ 20	Not Practical

This practicality test aims to evaluate the extent to which the developed device meets the aspects of practicality, which include: 1) Ease of use (setup, storage, and flexibility); 2) Efficiency of implementation time; 3) The attractiveness of the device to students; 4) Ease of interpretation by teachers and student; 5) Consistency of tool use in various variations. The assessment is carried out based on these factors (Sukardi, 2012). The following is a table containing the instrument grid used in the practical assessment by teachers:

Table 3. Expert Practicality Validation Sheet Grid

No.	Aspect of Practicality	Indicators	Number of Item
1	Ease of use	Ease of setting up the device.	1
		Convenience of storing the device.	2
		Flexibility in using the device under various conditions.	3
2	Efficiency of implementation time	Time required to set up the device.	4
		Time needed to use the device during learning activities.	5
3	Attractiveness of the Device	Visual appeal of the device for students.	6
		Level of student interest in using the device.	7
4	Ease of Interpretation	Teachers need ease of understanding the device.	8
		Ease of understanding the device for students.	5
		Clarity of the information produced by the device.	6
5	Consistency of Tool Use	The device consistently delivers the same results under different conditions.	7
		The device is durable when used in various learning environments.	8
Total			8

The student response questionnaire to Pascal's Law learning media was measured using a Likert scale. The results were calculated using equation (1) and then categorized in Table 5. Meanwhile, Table 6 showcases a comprehensive grid of the student response questionnaire utilized in this study, highlighting its importance and relevance in gathering valuable insights.

Table 4. Categories of Student Responses (Humaidi et al., 2021)

Scores (%)	Category
81 – 100	Very Positive
61 – 80	Positive
41 – 60	Enough
21 – 40	Negative
< 21	Very Negative

Table 5. Student Response Questionnaire Grid on Pascal's Law Learning Media

No.	Aspect of Student Response	Indicators	Number of Item
1	Appearance	The design of the learning media attracts students' attention.	1
		The visualization of the learning media helps students understand the material.	2
		The design of the learning media needs further improvement.	3
2	Ease of Use	The learning media is easy for students to use during the learning process.	4
		Students do not need a long time to understand how the learning media works.	5
		The features in the learning media are simple and not confusing.	6
3	Benefits	The learning media helps students understand the concept of Pascal's Law.	7
		The learning media provides clear visualizations related to Pascal's Law.	8
		The learning media offers a direct learning experience that is interactive and enjoyable.	9
		The learning media significantly improves student understanding.	10
Total			10

Furthermore, the analysis to determine the effectiveness of the learning media that has been developed can be seen from students' pretest and post-test, which are then measured by the N-Gain test.

$$< g >= \frac{S_{postest} - S_{pretest}}{S_{maksimum\ score} - S_{pretest}} \quad (3)$$

Where the ideal value is 100 (Meltzer, 2002). The N-Gain interpretation criteria refer to the Hake (1999) guide and can be seen in Table 7 (Hake, 1999).

Table 6. Effectiveness criteria for the learning media

Scores	Category
$1 > (< g >) \geq 0.7$	Very Effective
$0.7 > (< g >) < 0.3$	Effective
$(< g >) < 0.3$	Less Effective

The grid of questions that were used for the pre-test and the post-test can then be seen in Table 8.

Table 8. Grid of Questions for the Pre-test and Post-test

No	Sub Materials	Indicator	Number of Items
1	Understanding Pascal's Law.	Define Pascal's Law and explain its application in everyday life (C1).	1
2	Application of Pascal's Law in Hydraulic Systems.	Identify and describe the use of Pascal's Law in hydraulic systems, such as in car jacks (C2).	2
3	Pressure in Enclosed Fluids.	Explain how pressure is transmitted in a closed fluid based on Pascal's Law (C2).	3
4	Factors Affecting Pressure in Fluids.	Identify and analyze the factors that influence pressure in fluids according to Pascal's Law (C3).	4
5	Use of Pascal's Law in Means of Transportation.	Analyze and evaluate the application of Pascal's Law in transportation systems, such as hydraulic brakes (C4).	5
6	Working Principle of Hydraulic Jack.	Explain the working principle of a hydraulic jack based on Pascal's Law and apply it to real-life examples (C2).	6
7	Pressure Difference at Two Points in a Fluid.	Analyze how pressure differences occur at two points in a fluid based on Pascal's Law (C4).	7
8	Pascal's Law and Pipe Systems.	Explain and apply the relationship between Pascal's Law and a pipe system that carries fluids (C3).	8
9	Application of Pascal's Law in Industrial Machinery	Evaluate the application of Pascal's Law in industrial machinery, identifying practical examples (C5).	9
10	Pressure in Fluids and Equilibrium.	Synthesize the balance of pressure in fluids and explain its equilibrium according to Pascal's Law (C6)	10

RESULT AND DISCUSSION

Results of Needs Analysis Stage

Needs analysis aims to identify aspects required for the development of learning media, including material analysis, analysis of student difficulties in learning physics, and tools and mater1ials needed to support media development. The material chosen for media development is Pascal's Law, which is part of the grade XI material in the Merdeka Curriculum and the 2013 Curriculum. Based on the results of observations in one school, it was found that the limited learning media that can support the teaching and learning process is one of the main obstacles. In addition, students are also less interested in physics subjects, especially in Pascal's Law material, which causes low student interest and enthusiasm for learning. Other findings revealed misconceptions experienced by several students regarding Pascal's Law material. With this media-based experimental tool, students' interest in physics can increase and help them understand basic concepts in more depth.

During the needs analysis stage, research conducted by Rustiana et al. (2022) indicated that the limited availability of learning media supporting the physics learning process poses a significant challenge. Additionally, there is a low student interest in the material being taught, particularly regarding Pascal's Law. This aligns with the current study's findings, which also identify the lack of adequate learning media as a primary obstacle to enhancing students' understanding of Pascal's Law. Furthermore, this study revealed that some students experience conceptual errors related to Pascal's Law, echoing the conclusions of Pangke et al. (2021), which highlighted that conceptual errors are a common issue in physics education.

Results of Product Design

At the design stage, teaching aids are designed, starting from visual images to

purchasing materials and making products. The design of this tool is designed in such a way as to suit learning needs. The materials used include hard nylon, hose, Arduino Uno, load cell, acrylic, acrylic glue, fluid, weights, wooden boards, wall paint, laptops, and bolts. The combination of these materials is designed to create a teaching aid that is functional, efficient, and in accordance with the principles of Pascal's Law. The following is a design plan made using Canva.

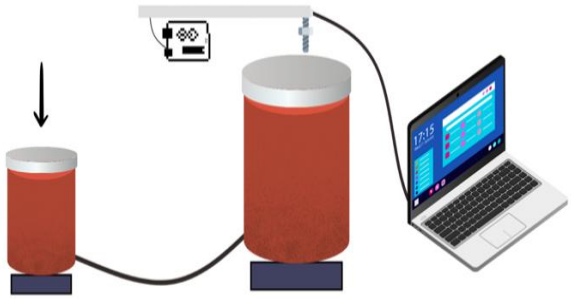

Figure 2. Design of Pascal Law Learning Media Based on Arduino Uno

In the design stage, this study developed a teaching aid to display visualizations following the principles of Pascal's Law, using Arduino Uno and Load Cell sensors. The results of this design differ from the research of Nabil et al. (2023), which emphasized the use of simpler technology to increase student engagement. Meanwhile, the design of the teaching aid used in this study obtained a very good physical quality score (93.33%), which was higher than that found in previous studies, indicating that good design plays an essential role in the successful implementation of learning media.

The study of Rustiana et al. (2022) indicated that the media used to understand physics concepts increased students' interest and understanding of the material. Additionally, the current study identifies the limited availability of learning media as a primary obstacle to enhancing students' understanding of Pascal's Law. Furthermore, conceptual errors related to Pascal's Law were identified as common issues in physics education, echoing the conclusions of Pangke et al. (2021).

Development Stage

In the development stage, internal trials were conducted to ensure that the experimental tool functioned as expected. The first physical trial revealed an issue where the fluid used, water, caused leaks in the piston. To resolve this, the fluid was replaced with baby oil, which has a higher viscosity, making it more effective in preventing piston leaks. Additionally, the Arduino coding was adjusted to improve the accuracy of the data and simplify the process of measuring force with a mass sensor. The final product of this tool, shown in Figure 3, illustrates the complete experimental setup, ready for use in teaching Pascal's Law.

Figure 3. Visualization of the Final Product of Pascal Law Learning Media Based on Arduino Uno

The results of this study showed that the Arduino Load Cell-based learning tools significantly increased students' understanding of Pascal's Law, with an average N-Gain increase of 63%. The tools developed in this study allow for a deeper understanding of Pascal's Law by utilizing accessible and affordable technology, specifically the Arduino Uno.

When comparing the findings of this study with those of other researchers, several similarities and differences emerge. For instance, Ardiansyah (2023) developed a physics learning aid based on constructivist principles, aimed at improving students' understanding of fluid statics, including Pascal's Law. The tools he developed, such as various types of tubes (straight, bent, and inclined) and hydrostatic

pressure devices, also aimed to provide a more tangible understanding of fluid properties and laws like Pascal's and Archimedes'. The major difference, however, lies in the complexity of the tools: Ardiansyah's design involved physical components like tubes and liquids, while this study incorporated a more streamlined approach using Arduino-based technology, which offers real-time data analysis and more direct interaction for students.

Similarly, Maryanti (2022) described the development of experimental tools to teach fluid dynamics, focusing on simple materials like syringes, hoses, and liquid substances such as syrup and oil. Her approach, which involved a series of manual steps to build the experimental setup, allowed students to observe the effects of pressure changes in confined fluids. While Maryanti's work successfully demonstrated fluid behavior in the context of Pascal's Law, it lacked the computational and data-driven aspect that Arduino technology adds to the current study. The use of Arduino and Load Cell sensors in this study provided more precise measurements of force, which is a key advantage over the more observational approach in Maryanti's design.

Nabil (2023) developed an experimental tool similar to this study's focus on Pascal's Law, using components like glass syringes, acrylic materials, and water or oil-based fluids. In his design, an important adjustment involved replacing a capillary pipe with a plastic tube to reduce friction. While his study aimed to create tools that align with Pascal's Law, the integration of Arduino-based sensors in this study makes it stand out. Nabil's design focused on mechanical components for observing pressure differences, whereas this study leveraged sensors and digital data collection to enhance precision and ease of use for students.

In conclusion, while all three studies emphasize the importance of hands-on learning and experimental tools for teaching Pascal's Law, this study's use of Arduino and Load Cell technology offers unique advantages in terms of data accuracy, real-time analysis, and ease of use. The findings from the development phase, including the use of baby oil for better viscosity and the adjustments made to Arduino coding, demonstrate that integrating affordable yet sophisticated technology can significantly enhance students' conceptual understanding of fluid dynamics and related physical laws. The results are consistent with the research of Ardiansyah (2023), Maryanti (2022), and Nabil (2023), while offering an innovative approach to achieving more precise, interactive, and engaging learning experiences.

Implementation Stage

In the Implementation Stage, the developed teaching aids are applied for use in learning activities at school. Students who are the subjects of the research have studied the topic of Pascal's Law before. Hence, they already have a basic understanding of the material before participating in the experiment with the newly developed teaching aids.

Before experimenting with the teaching aids, students were given a pre-test consisting of ten questions related to Pascal's Law. This pre-test aims to measure students' initial knowledge of the material. The results of this pre-test provide an overview of students' understanding before they are involved in using Arduino Load Cell-based learning media.

After the pre-test, students were invited to conduct an experiment using the developed teaching aids. In this experiment, they process the data obtained, analyze the results, and draw conclusions about Pascal's Law through the teaching aids. This Arduino-based teaching aid allows students to measure force and visualize physics concepts more realistically, which is expected to improve their understanding.

After conducting the experiment and understanding the concept of Pascal's Law with the new teaching aids, students were given a post-test consisting of the same questions as the pre-test. The purpose of the post-test is to assess the increase in students' understanding after experimenting. The comparison between the pre-test and post-test results provides an overview of the progress achieved by students in understanding the material.

From the results recorded in Table 9, a comparison between the pre-test and post-test scores of each student can be seen. Based on the results of the N-Gain analysis, which is used to measure how much students' understanding has increased, it can be concluded that Students S3, S6, and S7 showed excellent results with high N-

Gain (more than 0.75), which means that their understanding of Pascal's Law material increased significantly after using the teaching aids. Students S1, S2, and S4 experienced a more moderate increase (N-Gain between 0.33 and 0.50), which shows that although there was an increase in understanding, the results were still in the moderate improvement category. Student S5 also showed results with a low N-Gain category; although there was a slight increase, the increase was not very significant.

Overall, the N-Gain results showed a pretty good increase in student learning, with an average increase of 63%. This means that most students experienced progress in their understanding after using Arduino-based teaching aids. Although the average shows an increase, there is quite a significant variation between student scores. Some students obtained high N-Gain, while others only obtained low N-Gain. This shows that although the teaching aids are practical, other factors such as motivation, student involvement in the learning process, and prior knowledge background can affect the final results.

From the results of the N-Gain analysis obtained in this study, a comparison can be made with the findings of three previous studies. Research by Pangke et al. (2021) showed that using Arduino-based teaching aids also increased student understanding, with an average N-Gain value of around 0.92, included in the very high increase category. Meanwhile, Nabil et al. (2023) reported different results, with the average pretest and posttest scores increasing from 77 to 82.5, with an N-Gain value of 0.24, included in the low category. In this study, the N-Gain results showed more significant variations between students, with some students achieving high N-Gains (more than 0.75), such as S3, S6, and S7, which indicated very good understanding after using Arduino Uno-based learning media. On the other hand, some students showed lower improvements, with N-Gains between 0.33 and 0.50, which were included in the moderate improvement category. Overall, the average N-Gain in this study was 0.63, which is in the moderate to high improvement category but with significant variation among students. This comparison shows that although previous studies have shown comparable results in improving student understanding through technology-based media, this study shows more considerable variation in individual understanding improvements. This could be due to several factors, such as differences in the tools used, student involvement in the experimental process, and the more diverse background of students' prior knowledge. However, overall, the results of this study strengthen previous findings that show that technology-based learning media, such as Arduino Uno, can improve students' understanding of physics concepts, especially in Pascal's Law material.

Based on the findings in the N-Gain analysis, students who are less active or not well involved in the experiment and data processing tend to show lower improvements. Therefore, active participation has a significant effect on learning outcomes, indicating the importance of student involvement in every stage of learning to maximize the results achieved.

Table 9. Recapitulation of pre-test, post-test, and n-gain results

Student Code	Pre-test	Post-test	N-gain	Category
S1	70	80	0.33	Moderate
S2	40	70	0.50	Moderate
S3	50	90	0.80	High
S4	70	80	0.33	Low
S5	70	90	0.67	Low
S6	60	90	0.75	High
S7	90	100	1.00	High

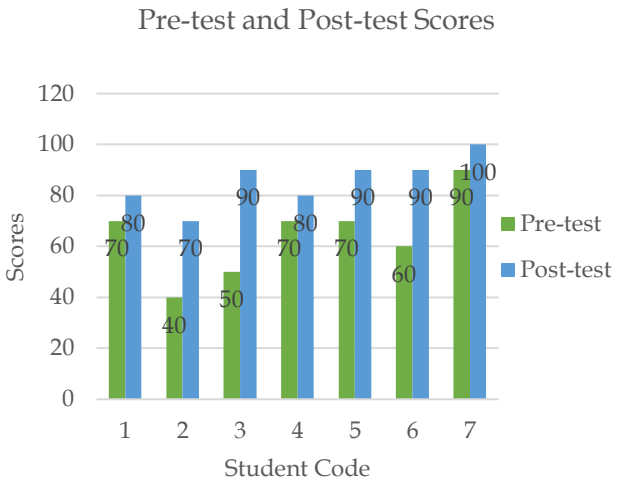

Figure 4. Student learning outcomes on the topic of Pascal's Law after using the media developed

From the results of the study (see Table 9), it was found that two students almost entered the low category in learning improvement, although they were still in the moderate category, namely with an N-Gain value of 0.33. This indicates that although there was improvement, there were certain factors that limited their progress. After examining the pre-test and post-test questions, and analyzing their relevance to the Education Performance Report (LKPD), it was found that all of these aspects were actually good and relevant. The questions created had good discriminatory power and the level of difficulty was all in the moderate and easy categories after analyzing the items.

However, after conducting a deeper analysis, it turned out that these two students did not follow the learning well. They were not active in filling out the LKPD, so when it was time to fill out the post-test questions, they felt confused and had difficulty. This shows that although the exam questions are relevant and of good quality, active participation in the entire learning process, including filling out the LKPD, has a significant impact on student performance in facing the final evaluation.

This confirms that in addition to the quality of the exam questions, student participation and involvement in the entire learning process also play a crucial role in achieving optimal learning improvement. Therefore, students need to be fully involved in every aspect of learning, both in experiments and in other tasks, to maximize their understanding of the material and exam results. Active participation can be the key to ensuring that students not only remember the material, but also truly understand it, which in turn will improve their overall learning outcomes.

Next, an analysis of the validity test was carried out. The validity test was carried out to evaluate the feasibility and validity of the Pascal's law teaching aids based on the Arduino Uno Load Cell that had been developed. This test includes an assessment of the material aspects, the quality and appearance of the teaching aids, and the benefits of the teaching aids in learning regarding the media aspect by media experts and material experts. Media experts conducted the assessment using a scale of 5 as a reference value. In addition to assessing the feasibility and validity of the teaching aids, this assessment also aims to obtain comments and suggestions for improvement for the teaching aids that have been made. The results of the media and material assessments can be found in Table 10.

Table 10. Recapitulation of the validity of Pascal's Law learning media based on arduino load cells

Aspects	Scores	(%)	Category
Learning materials	13	86.67	Valid
Quality and appearance of props	14	93.33	Valid
Benefits of teaching aids in learning	13.33	88.89	Valid
Average (%)	**13.44**	**89.63**	**Valid**

Table 10 shows a recapitulation of the results of the validity evaluation of the Pascal's Law learning media based on Arduino Load Cell. This evaluation was conducted to assess how valid and effective this learning media is used in the teaching and learning process. The assessment was conducted based on three main aspects: learning materials, quality and appearance of teaching aids, and benefits of teaching aids in learning. Each aspect was assessed based on a percentage score indicating the extent to which the learning media met the validity criteria.

In the Learning materials aspect, the learning media developed was assessed in terms of the suitability of the material presented with the learning objectives, namely Pascal's Law. The evaluation results showed a score of 86.67%, which means that the material presented in the learning media was appropriate and relevant to the topic being studied. In other words, this media is effective in conveying important concepts regarding Pascal's Law, helping students to understand the material more easily. This score is included in the valid category, indicating that the learning materials can be accepted and used well in learning.

The Quality and appearance of props aspect assesses the physical quality and design of the teaching aids used in the experiment. The results showed a score of 93.33%, indicating that the Arduino Load Cell-based teaching aids have an attractive appearance and very good quality.

The design of the teaching aids is clear, easy to understand, and can directly demonstrate physics concepts, making this tool very effective for use in learning. This high score indicates that the teaching aids are not only functional but also interesting for students, thus increasing their involvement in the experiment.

Then, the Benefits of teaching aids in learning aspect focuses on the extent to which the teaching aids help students understand the concept of Pascal's Law. A score of 88.89% indicates that the Arduino-based teaching aids are very useful in learning, especially in clarifying physics theories that were previously difficult to understand. This media allows students to directly see and measure forces, which helps them understand concepts more easily. The results of this evaluation indicate that this teaching aid provides great benefits in improving students' understanding of the material being taught.

Overall, the Pascal's Law learning media based on Arduino Load Cell obtained an average score of 89.63%. This means that this media can be categorized as valid and effective for use in the learning process. This average indicates that the teaching aids and materials used meet the expected criteria in supporting students' understanding of Pascal's Law.

Next, Table 11 presents comments and suggestions for improvement given by experts related to the Pascal's Law learning media based on Arduino Load Cell. These comments and suggestions are very important to improve the quality and effectiveness of learning media in order to support better student understanding. These comments indicate that the teaching aids are appropriate and effective in constructing students' knowledge about the basic principles of Pascal's Law, which involve the concepts of pressure, force, and their application in everyday life. This media helps students to connect theory with practice through experiments conducted, allowing them to see firsthand the application of the laws of physics.

Despite receiving positive comments, experts provided suggestions for improvement to improve the accuracy of the data generated by the teaching aids. They suggested that the accuracy of the data obtained during the experiment be improved, to ensure that Pascal's Law is applied more appropriately in the context of the experiment. This is important because data accuracy is a key factor in the validity of experimental results, which in turn can affect student understanding. If the teaching aids do not provide sufficiently accurate data, students may have difficulty understanding the relationship between theory and practice, or even get the wrong understanding.

Table 11. Comments and Suggestions for Improvement by Experts

Validation	Comments	Suggestions
Arduino Load Cell Based Pascal's Law Learning Media	This learning media can be used to construct students' understanding of Pascal's Law.	Modify data accuracy to ensure that Pascal's Law applies.

Furthermore, analysis was conducted to determine the practicality of the developed learning media. This practicality questionnaire was filled out by practitioners (teachers) to obtain information on the extent to which the developed teaching aids were practical based on teacher predictions and considerations after being used during the learning process (Revita, 2019). Overall, the results of the practicality questionnaire filled out by teachers can be seen in Table 12 below.

Table 12. Recapitulation of the practicality of Pascal's Law learning media based on arduino load cells

Aspect	Scores (%)	Category
Benefits	85.00	Very Practical
Ease of Use	79.20	Practical
Ease of Learning	77.00	Practical
Satisfaction	84.67	Very Practical
Average (%)	**81.47**	**Very Practical**

Table 12 presents the results of the evaluation of the practicality of Pascal's Law learning media based on Arduino Load Cell. This evaluation covers four main aspects, namely benefits, ease of use, ease of learning, and student satisfaction with the teaching aids. The results of this evaluation provide a clear picture of the extent to which this learning media can be applied in real classroom learning contexts.

In terms of benefits, this learning media obtained a very high score, namely 85%, which is included in the very practical category. This shows that students feel that the Arduino Load Cell-based learning media provides significant benefits in the learning process, especially in building their understanding of Pascal's Law. This media can clarify complex physics concepts by visualizing the basic principles of the law, which makes it easier for students to understand the material.

In terms of ease of use, this media scored 79.20%, which is included in the practical category. Although there is still room for improvement, this score shows that this learning media is quite easy for students to use. The use of Arduino Load Cell-based teaching aids does not require complicated technical skills, so students can efficiently operate them during experiments. This also shows that this tool can be well integrated into learning activities that do not require complex additional equipment.

In terms of ease of learning, this media scored 77%, which is also included in the practical category. This score indicates that students find it relatively easy to learn the concept of Pascal's Law using this media. Arduino-based experiments provide a more interactive and practical learning experience, which accelerates students' understanding of the material being taught. However, some students may still need further guidance in using this teaching aid to maximize the learning process.

The aspect of satisfaction scored high, namely 84.67%, which indicates that students are delighted with the use of this learning media. This media is not only effective in helping students' understanding, but also provides a fun experience and motivates students to be more active in learning. This high satisfaction reflects that students feel interested and motivated to use this media further, which in turn improves the overall learning process.

Overall, learning media using Arduino Load Cell has proven to be effective and practical in helping students understand Pascal's Law. Although several aspects can still be improved, such as increasing the ease of the learning process, this media provides a reasonably adequate and enjoyable learning experience. High scores on the aspects of benefits and satisfaction indicate that this media is an excellent choice to be implemented in physics learning in schools. The practicality of this media is reflected in its ease of use, which can be evaluated through its implementation (Susanti & Maulana, 2023). A product is considered practical if the user feels that the product can be used well. Teaching aids, including this learning media, are considered practical if they are able to attract students' attention and interest (Dzulkifli, 2021; Puspitarini & Hanif, 2019; Winarto et al., 2020).

Then, the student response questionnaire analysis was also conducted, which can be seen in Table 13. Table 13 shows the results of student responses to Arduino Load Cell-based learning media to understand Pascal's Law. Based on the responses given by students, overall, this learning media received a positive response, with an average score of 76.79%.

The appearance aspect received a reasonably high score, namely 76.19%, which indicates that this learning media is liked by students in terms of its design and visualization. An attractive appearance can attract students' attention and create a more enjoyable learning atmosphere. However, it is possible that some students feel that the appearance can still be improved further to make it more attractive and make it easier for them to understand the material.

The ease of use aspect received a score of 70.24%, which is also included in the positive category. This shows that most students can use this media easily in the learning process. However, this score is slightly lower than the appearance and benefits, which indicates that some students still feel that it takes time to get used to the existing tools and user interfaces, or some features can be simplified to improve ease of use.

The benefit aspect obtained a very high score, namely 82.14%, which shows that the majority of students feel that this learning media is beneficial in understanding the concept of Pascal's Law. This great benefit reflects that Arduino Load Cell-based learning media is able to significantly improve student understanding, provide clear visualizations, and allow students to interact directly with physics experiments that make the material more accurate and easier to understand.

Overall, the results of student responses show that Arduino Load Cell-based learning media are well received, with the categories "positive" in the appearance aspect, ease of use, and "very positive" in the benefits aspect. This shows that this media is effective in supporting the learning process, although there is still room for improvement, especially in ease of use to make it easier for students to operate the tool.

Table 13. Student responses to the developed Pascal's Law learning media

Aspects	(%)	Category
Appearance	76.19	Positive
Ease of Use	70.24	Positive
Benefits	82.14	Very Positive
Average (%)	**76.79**	**Positive**

The active involvement of students in experiments was found to significantly improve their understanding, aligning with the findings of (Nabil et al., 2023). Although most students showed good increases in understanding, variability in results was observed depending on the level of student participation in the learning process, indicating the importance of engagement in hands-on activities.

Evaluation Stage

In the Evaluation Stage, an assessment was carried out on the effectiveness of the Arduino Load Cell-based learning media developed to teach Pascal's Law. The evaluation results showed that students' responses to the teaching aids were very positive.

Based on observations of several aspects, the average score obtained reached 76.79%, which is included in the positive category. This result is higher than the findings of previous studies, as reported by Nabil et al. (2023), which showed that although the teaching aids used were relevant, their level of validity did not always reach a very high value. The advantage of this study lies in the validity of the tool, which has been proven effective in supporting the physics learning process.

The appearance aspect scored 76.19%, which places it in the positive category. This shows that the design of this learning media is attractive to students and quite effective in attracting their attention. However, there is still potential to improve the visual aspects and user interface to make it more attractive and easy for students to understand so that they can be more comfortable using it. The ease of use aspect scored 70.24%, which is also in the positive category. Although the majority of students feel that they can use this tool relatively quickly, some students may have a little difficulty adapting to the teaching aids or interfaces used. This can be an area for improvement, primarily by simplifying procedures or providing more explicit guidance on how to operate the tool. The benefits aspect scored the highest, namely 82.14%, which is included in the very positive category. This shows that students feel that this learning media is beneficial in understanding the concept of Pascal's Law. Arduino Load Cell-based teaching aids allow students to be directly involved in physics experiments, provide more straightforward visualizations of the physics concepts they are learning, and improve their understanding of the material. These benefits are in line with the findings of research by Matsun et al. (2022) and Permatasari et al. (2019), which state that the use of teaching aids in learning can increase student motivation and make the learning process more engaging and interactive.

With the results of this evaluation, it can be concluded that the Arduino Load Cell-based Pascal's Law teaching aid is effective in supporting physics learning. Although some areas can still be improved, especially related to ease of use, overall, this teaching aid has a positive impact on improving student understanding. Therefore, this teaching aid can be recommended for use in physics learning activities in schools as an innovative and enjoyable means to improve the quality of learning.

The study emphasizes the importance of aspects such as student activity, the quality of teaching aids, and ease of use as determining factors for the success of learning media. The findings demonstrate that Arduino-based media can serve as an efficient and effective alternative for supporting students' understanding of complex concepts like Pascal's Law, contrasting with previous studies that employed more complex or expensive tools.

CONCLUSION

Based on the research results, the development of Arduino Load Cell-based learning media for Pascal's Law material has proven effective in improving students' understanding. This learning media received positive assessments from experts and students through the stages of needs analysis, design, development, implementation, and evaluation. The results of expert validation showed that this learning media met the valid criteria with an average percentage of 89.63%. Furthermore, students' responses to this learning media were also very positive, with an average rate of 76.79%, especially in the benefits aspect, which reached 82.14%. Although some aspects still need to be improved, such as ease of use, this Arduino Load Cell-based learning media has proven effective in helping students understand the concept of Pascal's Law and can be recommended for use in physics learning in schools. Based on these results, it is recommended that further development be carried out to improve the ease of use aspect and enrich the variety of experiments that can be carried out using this media so that it can further facilitate students' understanding of Pascal's Law material and improve their learning outcomes. This study successfully answered the research question by showing that the use of Arduino Load Cell-based learning media has a positive impact on improving student learning outcomes in Pascal's Law material, in line with previous research findings that show the potential for developing technology-based learning media in enhancing students' understanding of physics concepts.

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