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Development of a Liquid Density Measurement Device Based on the Integration of Fluid Pressure and Spring Elasticity as an Alternative Physics Demonstration Tool

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ABSTRACT

Physics learning in schools requires the availability of adequate measuring instruments to enable students to conduct empirical observations and connect theoretical concepts with real-world phenomena. One of the essential instruments in fluid mechanics instruction is a device for measuring fluid density. However, limitations in laboratory facilities often result in the unavailability of such instruments, thereby reducing the effectiveness of practical learning activities. This study aims to develop a simple, low-cost, and easily replicable liquid density measurement device by integrating the principles of fluid pressure and spring elasticity as its measurement mechanism. This research employed a development methodology consisting of three main stages: (1) the design phase, which focused on determining the working principles and selecting components that could be constructed using readily accessible materials; (2) the development phase, involving the fabrication of a prototype using simple materials; and (3) the testing phase, conducted to evaluate the accuracy and consistency of the measurement results. Water was selected as the test fluid because its standard density value is widely recognized as a reference. The resulting prototype operates by converting changes in hydrostatic pressure into spring displacement, which is subsequently calibrated to obtain the corresponding density value. Experimental evaluation demonstrated that the device produced a density measurement of 0.95 g/cm³ with an error margin of 0.05 g/cm³ relative to the reference value, indicating that the instrument is sufficiently accurate for instructional purposes. Overall, this development provides a practical contribution to physics education by offering an affordable and functional alternative laboratory instrument with strong potential to enhance students' experimental activities and deepen their understanding of fluid mechanics concepts.

Keywords: *measurement device, fluid density, hydrostatic pressure, spring elasticity.*

INTRODUCTION

Physics learning at the senior secondary school level possesses unique characteristics because it requires the integration of conceptual understanding, scientific process skills, and empirical experience through laboratory activities. As an experimental discipline, physics emphasizes that comprehension of abstract concepts such as fluid pressure, buoyant force, elasticity, and density can be achieved more effectively when supported by appropriate teaching aids and relevant demonstration instruments (Taşdere & Kaya, 2023). However, in practice, many schools continue to face limitations in laboratory facilities, particularly in terms of simple, affordable, and student-friendly instruments for measuring fluid density (Lowe et al., 2013). These constraints often result in learning processes that are predominantly theoretical and lacking in experimental activities, thereby reducing students' opportunities to develop scientific skills optimally (Chung et al., 2019). The availability of liquid density measurement tools in schools typically relies on standard instruments such as pycnometers, hydrometers, or digital balances. Although these instruments provide high accuracy, they are frequently underutilized in school settings due to several challenges, including relatively high cost, frequent calibration requirements, susceptibility to damage, and the complexity of operating procedures that may be unsuitable for the senior high school level (Duncombe & Yinger, 2011). This situation creates a gap between the competencies mandated by the *Merdeka Curriculum*, which emphasizes experiment-based learning, and the actual condition of laboratory infrastructure in many schools.

One of the essential physical quantities taught at the senior high school level is the density of fluids. The concept of density is closely related to various other topics, including hydrostatic pressure, Archimedes' principle, fluid dynamics, and its numerous real-world applications such as in the food industry, oil and gas processing, and water quality analysis. However, instruction on this topic often relies primarily on lectures and mathematical derivations without providing students the opportunity to directly perform fluid density measurements (Albarracín & Gorgorió, 2018). The lack of simple, innovative, and classroom-friendly demonstration tools limits the potential to reinforce conceptual understanding through experimentation (Chowdhury et al., 2019). Within the context of developing learning tools, the innovation of measurement devices that integrate concepts of fluid mechanics and elasticity represents a promising approach. Fluid pressure and the elastic force of a spring are fundamental concepts in mechanics, and they share a causal relationship that can be integrated into a single measurement instrument. The fluid pressure, which depends on the density of the liquid, can be converted into a force exerted on a spring; thus, the change in the spring's length can serve as a quantitative indicator of the fluid's density (Kovačević et al., 2021). This integrative approach is not only conceptually relevant but also enables the design of a simple, economical, and easily replicable device for both teachers and students.

The integration of fluid pressure and spring elasticity concepts within a single measuring instrument offers a valuable opportunity for phenomena-based learning. Students do not merely observe changes in spring length; they also learn to connect these observable phenomena with the physics equations they have previously studied, such as $P = \rho g h$ for fluid pressure and $F = kx$ Hooke's law (Uhden et al., 2012). Consequently, this instrument serves as a conceptual bridge that links theoretical principles with physical reality in a more intuitive manner. This is aligned with the aims of modern science education, which emphasize scientific reasoning, problem-solving skills, and science literacy (Turiman et al., 2012). Furthermore, the development of a density-measurement device based on the integration of fluid pressure and spring elasticity is crucial because it addresses two major challenges simultaneously: the limited availability of measurement instruments in school laboratories and students' insufficient empirical learning experiences. Such a device possesses substantial educational value, as it concretely visualizes mathematical relationships, provides hands-on measurement experiences, and facilitates the development of students' critical thinking skills (Xu, 2025). Additionally, this instrument is versatile, as it can be used both as a demonstration tool and as an individual laboratory apparatus, making it highly adaptable to various instructional methods.

Recent research trends in physics education indicate an increasing demand for instructional apparatuses that are not only functional but also pedagogically grounded. Numerous studies have shown that demonstration tools based on integrated conceptual frameworks can enhance students' conceptual understanding, reduce misconceptions, and strengthen their engagement in learning activities (Tong et al., 2025). However, research specifically addressing the development of density-measurement instruments that integrate fluid pressure and spring elasticity remains very limited. Most existing studies focus on the development of digital or simulation-based media, while the design of simple physical experimental tools has not yet received sufficient attention (Wang et al., 2025). In the context of Indonesian education, the development of inexpensive, practical, and conceptually grounded experimental instruments is highly strategic for supporting equitable learning quality across schools. Many schools located in remote areas or operating with limited budgets are unable to provide expensive standard laboratory instruments (Effendi & Sterzer, 2024). Therefore, a density-measurement device developed using simple materials and grounded in fundamental physics concepts can serve as a viable alternative solution, enabling teachers to implement experiment-based learning without relying on costly laboratory facilities.

On the other hand, curricular demands for scientific literacy and inquiry-based activities necessitate that teachers provide authentic learning experiences (Kotsis, 2024). By utilizing an innovative and user-friendly liquid density measurement device, students can develop essential skills in conducting measurements, analyzing data, and independently interpreting physical phenomena. This instrument also supports Project-Based Learning and Problem-Based Learning approaches, in which students may be guided to test various fluid samples, compare the results, and draw scientific conclusions based on empirical data. Given these considerations, the development of a liquid density measurement device based on the integration of fluid pressure and spring elasticity becomes both relevant and necessary as an effort to introduce a simple yet effective physics demonstration tool for senior high schools. This development not only provides an alternative laboratory instrument but also opens up opportunities for further research concerning the device's validity, reliability, practicality, and instructional effectiveness in real classroom contexts. Thus, this study makes a significant contribution to the advancement of physics education, particularly by providing an integrative concept–based experimental tool that enhances the quality of physics learning at the senior secondary level.

LITERATURE REVIEW

Liquid Density

The study of liquid density constitutes a fundamental basis for understanding the properties of fluids, as this quantity determines the compactness of particles within a given volume (Petrosino & Mann, 2017). In general, density is defined as $\rho = \frac{m}{V}\ the\ mass\ per\ uni,$ representing the distribution of mass within a fluid and serving as a central parameter for analyzing both hydrostatic and fluid dynamic phenomena. Livescu (2020) emphasizes that variations in density influence fluid stability in both closed and open systems, making it a primary variable in many fluid-physics models. This foundational understanding provides the groundwork for explaining a wide range of physics applications in both educational and engineering contexts. The relationship between density and hydrostatic pressure is an advanced concept often examined in fluid mechanics. Hydrostatic pressure, expressed as $P = \rho g h$, demonstrates that the greater the density of a liquid, the greater the pressure exerted at a given depth (Mao et al., 2018). Findings by Abubakar et al. (2015) indicate that even small changes in density can produce significant variations in pressure gradients, particularly in stratified fluid systems such as water–oil or water–saline layers.

From the perspective of physical properties, the density of liquids also depends on thermodynamic parameters, particularly temperature. Generally, an increase in temperature results in a decrease in density because intermolecular spacing becomes wider (Burt et al., 2014). Li and Sun (2021) reported that the influence of temperature on fluid density can range from 0.5% to 3%, depending on the type of liquid, and this factor becomes especially critical for industrial fluids such as lubricants and cooling media (Mallepally et al., 2018). Therefore, in both educational and applied research contexts, density measurements must consistently account for temperature conditions to ensure data accuracy and experimental reliability. In laboratory activities or instructional demonstrations, liquid density can be measured using various approaches, ranging from simple techniques to high-standard instruments. At the secondary education level, direct measurement based on the difference between mass and volume is the most accessible technique (Qiu et al., 2015). However, Jazaei (2022) demonstrated that the U-tube and hydrometer methods provide higher precision because they utilize differences in hydrostatic pressure or buoyant force as their measurement principles. These instruments enable educators to offer more accurate and standardized experimental experiences, thereby strengthening students' understanding of density concepts. Variations in liquid density also have significant implications for physical phenomena and engineering applications. Water, oil, alcohol, and biological fluids each possess distinct densities, resulting in natural stratification phenomena such as the separation of fluid layers. For instance, the density of water is approximately 1 g/cm³ (Ardekani et al., 2017).

Fluid Pressure and Spring Elasticity

Fluid pressure is a fundamental physical quantity that describes the force per unit area exerted by a fluid on a surface, mathematically expressed as $P = \rho g h$. This concept plays a crucial role in understanding how both static and moving fluids exert forces on objects and containers. Janus and Ulanicki (2017) emphasize that the distribution of fluid pressure governs flow behavior, surface stability, and the design of hydraulic systems. Consequently, fluid pressure serves as a central component in engineering physics analyses as well as educational experiments, including the design of measurement instruments and instructional demonstrations. In educational and introductory experimental contexts, the relationship between fluid pressure and fluid density is particularly highlighted, as density becomes the primary variable controlling pressure increases with depth (Weiqiang et al., 2016). Research by Mukhaimer et al. (2015) demonstrates that even slight variations in density can significantly impact pressure gradients, particularly in stratified fluid systems, such as water–salt or water–oil combinations. This finding is highly relevant to the development of measurement devices based on fluid pressure principles, such as U-tube manometers, where pressure differences between fluid columns are used to determine the density or relative pressure of a liquid (Ehlers et al., 2019).

Meanwhile, spring elasticity represents a mechanical phenomenon that describes a spring's ability to return to its original form after experiencing an external force. The fundamental relationship governing spring elasticity is formulated in Hooke’s Law, $F = kx$, which states that the force applied to a spring is proportional to its elongation (Çoban & Çoban, 2020). Salomone and Cyrulies (2023) emphasize that elastic behavior is influenced by the spring constant, material structure, and internal stresses, making spring deformation a precise indicator for measuring external force variations. This understanding is essential in various physical measurement systems, including mechanical sensors. The integration of fluid pressure and spring elasticity becomes particularly relevant in the development of modern measurement instruments. The combined principles are commonly utilized in devices such as pressure gauges, diaphragm-based pressure sensors, and simple fluid-density measurement tools that rely on buoyant forces transmitted to a spring (Javed et al., 2019). Back and Carroll (2023) demonstrate that the use of springs as transducer elements provides high sensitivity to changes in pressure or force, making them suitable for educational measurement device designs. Such integration enables more accurate measurements, as the spring’s mechanical response can visually represent subtle variations in fluid pressure through corresponding changes in elongation.

METHOD

This study is a research and development initiative comprising three main stages: design, development, and testing of a liquid-density measuring instrument. In the design stage, the initial step involved determining the topic and the underlying physical concepts of the instrument, namely liquid density in relation to the principles of fluid pressure and spring elasticity. The selection of these concepts was intended to ensure that the resulting instrument possesses a strong theoretical foundation and can be effectively applied in physics instruction. Once the conceptual focus was established, an extensive literature review was conducted to examine the relevant theoretical frameworks, including the concept of density, the relationship between fluid pressure and depth, and the characteristics of spring elasticity as defined by Hooke's Law. This literature review was essential for ensuring that the instrument's design adhered to accurate scientific principles and aligned with previous relevant research. The subsequent stage involved designing a preliminary model of the instrument based on the theoretical analysis and user needs.

The second stage involved constructing the liquid-density measuring instrument. This process began with preparing all tools and materials specified during the design phase. The materials included a PVC pipe, glass adhesive, a glass tube, a glass cutter, a ruler, a rubber valve, a faucet, and a wooden support frame. Once all materials were prepared, the first step was cutting the PVC pipe to a length of 50 cm and the glass tube to 30 cm. Both components were then smoothed at their edges to ensure that no sharp surfaces would interfere with the installation of subsequent components or obstruct the flow of fluid within the instrument. The next step was assembling the internal components of the device. The ends of the spring were attached to a rubber valve, after which the entire spring–valve assembly was inserted into the glass tube. A faucet was then installed approximately 4 cm from the rubber valve to allow the instrument to regulate fluid flow and to provide an appropriate response to changes in pressure. Subsequently, the PVC pipe and the glass tube were joined using glass adhesive to secure both components firmly in place. This connection ensured that the fluid pressure could be transmitted effectively to the spring. Finally, the fully assembled instrument was mounted onto a support frame to position each component correctly and ensure structural stability.

The third stage involved refining and evaluating the liquid-density measuring instrument after its assembly was complete. At this stage, the entire device was thoroughly inspected to ensure that each component functioned properly and that no construction errors were present. The inspection focused on several critical aspects, including potential cracks in the tubes, loose or improperly sealed joints, and the presence of small perforations that could lead to fluid leakage during measurement. Identifying and rectifying these issues was essential to ensure that the instrument operated accurately and safely. Following the inspection, an improvement process was implemented to address any deficiencies identified. These refinements included adding additional glass adhesive to poorly sealed joints, replacing damaged components, or reinforcing the support structure to maintain the instrument's stability during operation. The final step in this stage was the testing of the measuring device to verify its performance relative to the initial design specifications. Water was used as the test fluid, as its density is well-established and easily compared with reference values. Testing with water enabled the researchers to evaluate the instrument's sensitivity, the accuracy of its readings, and the consistency of the spring's response to fluid pressure. The results of this evaluation served as the basis for determining whether the device was ready for application or required further refinement.

The testing procedure was conducted by pouring water into the larger tube of the instrument. The water then flowed into the smaller-diameter glass tube, exerting pressure on the rubber valve connected to a spring. The fluid pressure acting over a cross-sectional area A induced a compression of the spring by an amount Δx. As the water continued to fill the tube, the height of the water column h increased. This height was measured using a ruler affixed to the side of the larger tube. The value of h plays a critical role, as the hydrostatic pressure at depth h is directly proportional to the density of the water being measured. Meanwhile, the restoring force acting on the spring, described by Hooke's law, depends on the magnitude of the compression Δx and the spring constant k. Accordingly, the density of the water can be determined from the relationship between the hydrostatic pressure and the corresponding restoring force generated by the spring, as illustrated in Figure 1.

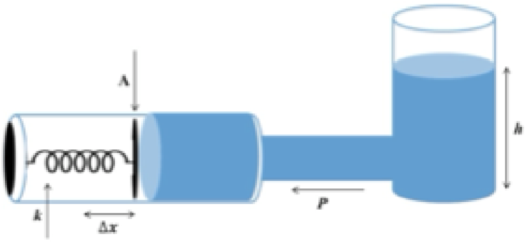

Figure 1. Design of the fluid pressure–spring elasticity interaction system

Conceptually, the fluid pressure acting on the valve, as shown in Figure 1, is formulated as Equation (1).

$$P = \rho g h \qquad (1)$$

Meanwhile, the spring force that arises due to compression Δx follows Hooke's law as in equation (2).

$$F = k\Delta x \qquad (2)$$

Since the fluid force pressing on the valve is equal to the spring force opposing it, a relationship is obtained as in equation (3).

$$\rho g h A = k\Delta x \qquad (3)$$

So the density of the liquid can be determined through equation (4).

$$\rho = \frac{k\Delta x}{ghA} \, (4)$$

This equation forms the basis for the operation of measuring instruments that utilize the integration of fluid pressure and spring elasticity to determine the density of a liquid in a practical and efficient manner.

RESULTS

Findings from the Design and Development of a Fluid Density Measurement Apparatus

The design of the liquid density measurement instrument was developed by adhering to fundamental physical principles, specifically the interaction between fluid pressure and the elastic response of a spring. The design phase began with the construction of a conceptual working scheme that illustrates how the fluid exerts pressure on the spring, which is subsequently transformed into a measurable and readable output. The initial visualization, produced through a detailed illustration, enabled both designers and prospective users to gain a comprehensive understanding of the instrument's operational concept before the prototype was fabricated. This illustration also functioned as a technical guide to ensure that each component of the instrument was assembled correctly and in accordance with the specified design parameters. Following the design phase, the instrument was further depicted in detail in Figure 2, which clearly presents the configuration of the spring, the fluid column, and the mechanism by which pressure is transmitted within the system.

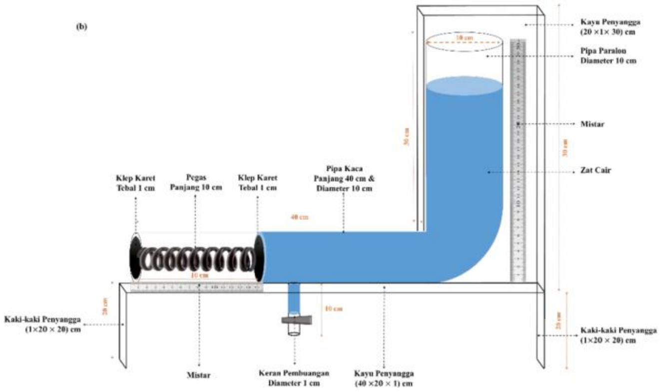

Figure 2. Design of a liquid density measurement instrument based on the integration of fluid pressure and spring elasticity

Figure 2 not only presents the physical structure of the instrument but also provides schematic information regarding the transmission pathway of fluid pressure—from the liquid surface to the resulting deformation of the spring. This schematic representation serves as a conceptual foundation for validating the measurement principles and ensuring that the device operates consistently with its underlying theoretical framework. Moreover, the illustration facilitates further development, both for research purposes and for practical applications in school laboratory activities. Meanwhile, the results of the development process are depicted in Figure 3, which shows the actual implementation of the integrated fluid-pressure and spring-elasticity mechanism. At this stage, the instrument has undergone a calibration process to ensure that the measured liquid density values can be verified with an acceptable level of precision.

Figure 3. Results of the development of a liquid density measuring instrument integrating fluid pressure and spring elasticity

Figure 3 highlights the functional dimensions of the instrument, including the scale-reading mechanism, the spring's response to incremental pressure changes, and additional components incorporated to enhance measurement stability and accuracy. Collectively, these features provide a comprehensive depiction of how the initial conceptual design is translated into an operational prototype. Overall, the progression from design to development demonstrates a strong alignment between theoretical principles and practical implementation. The illustrations presented in Figures 2 and 3 serve not only as visual documentation but also as empirical evidence that integrating fluid pressure and spring elasticity can yield a valid and applicable density-measuring device. This systematic approach ensures that each stage, from the conceptual workflow to prototype testing, mutually reinforces the others, resulting in an instrument that is functional, accurate, and accessible to users, particularly within physics education settings.

Results of Water Density Measurement

The measurement of water density using a fluid-pressure–spring–elasticity–based device demonstrates that the instrument exhibits a reasonably high level of validity in performing density assessments. The obtained water density value was 0.95 g/cm³, differing by only 0.05 g/cm³ from the standard density of water at room temperature, which is 1.00 g/cm³. This minor deviation indicates that the device is capable of generating data that closely approximates the reference value, thereby confirming its validity within the context of educational applications or demonstrations of fluid pressure and spring elasticity concepts. Nevertheless, the measurement results also reveal that the instrument's accuracy remains influenced by several technical factors, including potential imperfections in pipe connections, internal friction within the spring, and pressure variations caused by fluid turbulence during the filling process. These factors may introduce slight inconsistencies in the recorded values and should be addressed in future refinements to enhance measurement precision. The water density measurement results obtained using the developed instrument are presented in Table 1.

Table 1. Results of water density measurements

K $(g\ s^{-2})$	G $(cm\ s^{-2})$	A (cm^2)	H (cm)	Δx (cm)	ρ_{ukur} $(g\ cm^{-3})$	$\Delta\rho_{ukur}$ $(g\ cm^{-3})$	$\rho_{standar}$ $(g\ cm^{-3})$	$\bar{\rho}$ $(g\ cm^{-3})$	$\overline{\Delta\rho}$ $(g\ cm^{-3})$
165860,75	980	19.60	60	7.0	0.892	0.045	1.00	0.95	0.05
			50	5.7	0.984	0.055			
			40	4.6	0.993	0.065			
			30	3.2	0.921	0.035			
			20	2.5	0.907	0.045			
			10	1.4	1.036	0.050			

Based on Table 1, the measurement of water density was conducted repeatedly across various water column heights, ranging from 60 cm to 10 cm with a 10 cm decrement interval. This repeated measurement procedure was designed to assess the consistency of the device and to investigate how variations in fluid pressure resulting from changes in height affect the measured density values. Each height point produced data that revealed specific tendencies in the readings generated by the fluid-pressure–spring-elasticity–based measurement system. The results show that the greater the height of the water column, the lower the measured density value compared to the standard reference. This condition suggests that the increased fluid pressure at higher column heights induces slightly greater spring deformation, which in turn leads to lower density readings. Conversely, at lower water heights, the measured density values tended to increase and, in some cases, even exceeded the standard density of water. This phenomenon may occur because the reduced fluid pressure at lower heights results in minimal spring compression, causing the device to display a relatively higher density value. Overall, the average water density obtained from the measurements was 0.95 g/cm³. This value differs by only 0.05 g/cm³ from the standard density of water at room temperature, which is 1.00 g/cm³, indicating that the device possesses a reasonably good degree of accuracy. Although variations were observed at each height level, the relatively small deviation suggests that the instrument is capable of providing density estimates that are sufficiently close to the reference value. These findings support the conclusion that integrating fluid pressure and spring elasticity can serve as a simple yet functional alternative approach for measuring liquid density.

DISCUSSION

The research findings on water density measurement using an instrument based on the integration of fluid pressure and spring elasticity indicate that the device is capable of producing values reasonably close to the standard reference, namely 0.95 g/cm³ compared to 1.00 g/cm³ at room temperature. This result reinforces the notion that the measurement approach, which combines the principles of fluid pressure and spring compression, can serve as a valid alternative for physics demonstrations, particularly within senior high school educational settings. This is consistent with the findings reported by Ramli et al. (2022), who demonstrated that simple measuring instruments grounded in classical mechanics principles are capable of yielding consistent and sufficiently accurate data for instructional purposes, despite the presence of several technical factors that may influence measurement precision. Technical factors affecting accuracy, such as imperfect pipe connections and internal spring friction, are indeed common challenges in mechanical-based measurement tools. Previous research by Bhattad (2023) emphasized that even minor variations in the spring system or fluid channel can lead to significant differences in density measurements, especially for low-viscosity liquids. This suggests that although the instrument can approximate the reference value, its sensitivity to pressure fluctuations and spring motion requires careful consideration to enhance accuracy further, particularly when the device is intended for scientific experiments that demand high precision.

When compared with previous studies that employed pycnometer or aerometer methods, the fluid–pressure–and–spring–based approach offers distinct advantages in terms of demonstration value and student engagement. According to Salehi et al. (2022), laboratory instruments that visibly display the direct interaction between applied forces and mechanical responses can enhance students' conceptual understanding of pressure and density. In this context, the instrument developed in the present study provides added value because it enables density measurement to be observed visually through spring deformation, thereby allowing the concepts of fluid pressure and elasticity to be experienced tangibly. Furthermore, this study reveals that the instrument's accuracy is more optimal when measuring higher-viscosity fluids, such as lubricants. This phenomenon aligns with the findings of Datta et al. (2022), who reported that fluid-pressure–based measurement systems operate more stably in viscous liquids due to reduced turbulence and smaller fluctuations in applied force. Low-viscosity fluids tend to produce unstable spring responses due to vibrations or internal turbulence, making it difficult to maintain the spring compression value (Δx) consistently. These observations provide a basis for considering the type of fluid being measured as an important variable in the calibration and practical use of the instrument.

The influence of viscosity on measurement accuracy highlights the importance of designing measurement systems that take into account fluid dynamics. According to Hossain et al. (2024), integrating mechanical elements with fluid-based systems requires optimizing joints, valves, and springs to minimize undesirable external effects. In the present study, the fluctuations observed during water loading indicate that, although the instrument is valid, its accuracy could be further improved through technical modifications, such as employing a spring with a more suitable constant or incorporating a vibration-damping mechanism at the valve. From a pedagogical perspective, this instrument demonstrates substantial potential as a learning medium. As highlighted by Lin and Wu (2021), laboratory devices that integrate physical principles with mechanical visualization can enhance students' learning motivation and deepen their understanding of abstract concepts. This density-measuring instrument not only provides numerical output but also visually displays the relationship between fluid pressure and spring elasticity, allowing students to connect theoretical principles with direct observation. Such characteristics align well with experiment-based learning approaches that emphasize active student engagement.

However, comparisons with previous studies also reveal certain limitations regarding the operational scope of the instrument. The device tends to exhibit greater stability when measuring high-viscosity fluids, implying that its application to water or other low-viscosity liquids requires careful handling. This observation is consistent with the findings of Al-Rubaii et al. (2023), who reported that the accuracy of density measurements in low-viscosity fluids is highly dependent on instrument stability and the minimization of external disturbances. Accordingly, the present study contributes to the development of an alternative density-measurement device while simultaneously highlighting its experimental constraints. Further analysis indicates that although the measurement discrepancy is relatively small (0.05 g/cm^3), its sources can be traced to several factors, including irregularities on the valve surface, turbulence during filling, and the intrinsic characteristics of the spring. This phenomenon aligns with the conclusions of Afridi et al. (2023), who emphasized that the precision of mechanical–fluidic systems requires meticulous calibration and stringent control of external parameters. These insights provide valuable guidance for improving future versions of the instrument, such as enhancing spring quality, incorporating electronic pressure sensors, or modifying the geometric configuration of the fluid channel to achieve higher precision.

In the context of practical application, this study demonstrates that the instrument is well-suited for physics demonstrations in secondary school laboratories. Its advantage over conventional methods lies in its ability to visually illustrate the interaction between fluids and mechanical elements, enabling students to better comprehend the relationships among pressure, force, and density. Prior research by Banda and Nzabahimana (2021) supports this claim, showing that interactive laboratory media enhance students' conceptual understanding and scientific process skills, particularly in topics related to classical physics. Overall, the findings of this study affirm that integrating the principles of fluid pressure and spring elasticity provides a valid and engaging alternative for measuring the density of liquids. The device offers both pedagogical and technical benefits, demonstrating reasonably good validity for low-viscosity fluids and optimal accuracy for high-viscosity liquids. Although several factors influence its measurement accuracy, comparisons with previous studies indicate that the instrument holds substantial potential for further development, both in terms of design refinement and educational application. These results open avenues for future research focused on optimizing the device, expanding the range of measurable fluids, and integrating modern sensors to enhance measurement precision.

CONCLUSIONS

The findings of this study indicate that the liquid-density measuring instrument based on the integration of fluid pressure and spring elasticity was successfully designed and constructed using simple, inexpensive, and easily accessible materials suitable for secondary school environments. The instrument was able to measure the density of water at 0.95 g/cm³, differing by only 0.05 g/cm³ from the standard room-temperature value of 1.00 g/cm³. This result demonstrates that the device possesses sufficient validity for educational purposes, particularly for demonstrating the concepts of fluid pressure and spring elasticity, and it can serve as an interactive and pedagogically valuable laboratory medium. Nevertheless, the study also highlights several limitations related to measurement accuracy, which is still influenced by technical factors such as imperfect pipe connections, internal friction in the spring, and pressure fluctuations caused by fluid turbulence during the filling process. The device's dependence on stable fluid pressure and the spring's mechanical response make measurements of low-viscosity liquids, such as water, more susceptible to variation. This reinforces the finding that although valid for water, the instrument performs more optimally with higher-viscosity fluids, such as lubricants, where pressure stability and spring response tend to be more consistent. Based on these findings, future development of the device should consider technical optimizations, including improving pipe junctions, reducing internal friction, or incorporating vibration-damping mechanisms for the spring to enhance accuracy across a wider range of liquids. Additionally, this study provides a foundation for broader applications of the instrument in physics education, while emphasizing the importance of selecting fluids that align with the device's characteristics to achieve more consistent and representative measurements. These limitations provide valuable insights for subsequent research and the advancement of more precise density-measurement instruments for both educational and experimental purposes.

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