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Water Flow Driven by Air Pressure in a Simple Water Dispenser System as a Learning Medium for the Concept of Pressure: Pedagogical Advantages and Their Relation to Child-Friendly Learning

Zaky Febrian Syah, Salsa Aurelia Safitri, Chielsea Salasabila

Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia

*Correspondence to: *zakyfebrians@student.unnes.ac.id*

Abstract: Students' understanding of air pressure is frequently hindered by its abstract nature, as air cannot be observed directly. This development study aims to design and qualitatively test a simple instructional medium in the form of an air-pressure-based water dispenser system, to describe its pedagogical advantages, to compare it with previous research, and to relate it to the concept of child-friendly learning. The medium was constructed from a used plastic bottle, a balloon, a small hose, water, and a collecting container. Squeezing the balloon reduces the total volume of enclosed air so that, in accordance with Boyle's Law, the pressure inside the bottle increases and pushes water out through the hose. A descriptive exploratory method was employed through direct trials in five stages, complemented by a comparative review of previous studies. The results show that pressure applied to the balloon consistently drives water flow, whereas releasing the pressure weakens the flow until it stops. Based on these results and the literature review, the medium has the potential to offer six advantages: it is concrete and easy to observe, encourages active engagement, is low-cost and environmentally friendly, is contextual, may help reduce misconceptions, and supports project-based learning. These advantages align with the principles of child-friendly learning, namely being safe, participatory, developmentally appropriate, inclusive, and environmentally conscious. Quantitative measurement and trials with students are needed in the next stage.

Keywords: Air pressure; Instructional media; Simple teaching aid; Simple water dispenser; Child-friendly learning

Introduction

Air pressure is one of the fundamental concepts in physics education, describing the force exerted by air particles on a surface within an enclosed space. This principle is formally described by Boyle's Law, which states that, at constant temperature and for a fixed amount of gas, the pressure of a gas in a closed system is inversely proportional to its volume, expressed as $P_1V_1 = P_2V_2$ (Halliday et al., 2014). Although this concept is foundational and widely applied in everyday devices such as gallon dispensers, water pumps, spray devices, and syringes, students often struggle to understand it fully because air cannot be seen directly. This difficulty commonly arises when instruction is dominated by verbal explanation and mathematical formulas without concrete, observable experience.

Conceptual difficulties in the topics of fluids and pressure have been widely reported. A review of 111 articles published between 2015 and 2019 identified a large number of physics concepts that give rise to student misconceptions (Soeharto et al., 2019). In static fluids, Sholahuddin et al. (2019) reported misconceptions of 41.94% on the concept of hydrostatic pressure and 41.94% on the concept of pressure in fluids in closed systems among 31 senior high school students in Bandung. Simple practicum activities have been examined as one strategy for reducing misconceptions in static fluids (Pratiwi & Wasis, 2013), and misconceptions about hydrostatic pressure have been specifically diagnosed among senior high school students (Wijaya et al., 2016).

The limited availability of concrete media in physics instruction has long been a concern. The use of specially designed instructional media has been shown to significantly influence physics learning outcomes; groups taught with specially designed media achieved considerably higher learning outcomes than those relying solely on conventional media (Supardi et al., 2012). A positive influence of instructional media on learning outcomes has also been found when examined in relation to learning interest, although in the

context of social studies in elementary schools (Tobamba et al., 2019). More broadly, a survey of approximately six thousand students showed that interactive-engagement methods produced greater gains in conceptual understanding of mechanics than traditional methods (Hake, 1998).

The development of simple, low-cost teaching aids has been widely applied to help students understand abstract physics concepts, including pressure. Dewi et al. (2019) developed a teaching aid on the topic of pressure to train junior high school students' science process skills and concluded that the aid was suitable for use in learning. The use of used goods has also been developed for static fluids with the guided inquiry discovery learning model (Nuwairah et al., 2018), for science learning in elementary schools (Pambudi et al., 2018), and for capillarity as a solution for schools with limited equipment, especially in remote areas (Setyaningrum et al., 2018). Furthermore, the use of simple teaching aids within a project-based learning (PjBL) framework has been shown to improve higher-order thinking skills (HOTS), because designing and testing a device encourages students to think critically about the phenomena they observe (Sambite et al., 2019). A PjBL model based on simple teaching aids also effectively improved the critical thinking skills of pre-service physics teachers while deepening their mastery of the concepts they will teach (Widyaningsih & Yusuf, 2018).

On the other hand, the quality of learning is determined not only by cognitive achievement but also by the extent to which learning takes place in an environment that is safe, enjoyable, and respectful of children's rights. A child-friendly school is defined as an educational unit that is safe, clean, healthy, caring, and environmentally conscious, that guarantees the fulfillment of children's rights and protects them from violence, discrimination, and other mistreatment, and that supports children's participation in planning, policy, learning, and oversight (Menteri Pemberdayaan Perempuan dan Perlindungan Anak Republik Indonesia, 2014). At the level of instruction, a child-friendly model emphasizes student activity, opportunities to express ideas and display work, and learning by doing (Sudirjo, 2010). This idea is consistent with the cognitive development of primary-school-age children in the concrete operational stage, when conceptual understanding requires real objects (Marinda, 2020; Piaget & Inhelder, 1969).

Based on this background, the present author group, as students of the Physics Education Study Program, designed a simple instructional medium in the form of a water dispenser system utilizing the principle of air pressure. The medium was constructed from inexpensive, readily available materials (a used plastic bottle, a balloon, and a small hose) with a working principle that students can observe directly. The objectives of this study are (1) to design a concrete teaching medium for the principle of air pressure and to observe the relationship between applied pressure and the resulting rate of water flow; (2) to describe the pedagogical advantages of the medium and compare them with previous research; and (3) to relate the characteristics of the medium to the concept of child-friendly learning, so that students may develop a more meaningful conceptual understanding of pressure.

Methods

This study employed a descriptive exploratory approach through the rapid prototyping of a simple instructional medium, followed by direct trials to observe the device's performance and operating principle. This low-cost, design-and-build approach using recycled materials is widely used in the development of affordable physics teaching aids, as it is considered effective for producing concrete media that accurately represent the concept to be explained (Maharani et al., 2017).

The tools and materials consisted of: (1) a medium-sized used plastic bottle, serving as both the water container and the enclosed space in which the pressure change occurs; (2) a rubber balloon, tightly fitted over the bottle's mouth as the source of the pressure change; (3) a small hose attached to the side of the bottle as the water outlet channel; (4) water, as the fluid whose flow was observed; and (5) a small container to collect water flowing out through the hose.

The construction and testing procedure was carried out in five sequential stages: (1) tightly attaching the balloon to the bottle's mouth to prevent air leakage; (2) filling the bottle with a certain volume of water; (3) squeezing the balloon so that air is pushed and the volume of enclosed air decreases; (4) observing the

water flowing out through the hose as a result of increased pressure inside the bottle; and (5) releasing the pressure on the balloon to observe the resulting change in water flow rate. Each stage was observed and documented to ensure consistency of results.

Observations were conducted qualitatively, focusing on three main indicators: the condition of the balloon (squeezed or released), the pressure condition inside the bottle, and the condition of the water flow exiting through the hose (flowing strongly, weakening, or stopped). These indicators were analyzed to explain the cause-and-effect relationship between the applied pressure and the resulting fluid flow response.

To address the second and third objectives, a comparative review of previous studies was conducted. The literature was selected from journal articles and policy documents relevant to teaching aids made from used materials, fluid and pressure concepts, misconceptions, and child-friendly learning. Each study was compared in terms of the type of medium, the concept addressed, the subjects and methods, and the main findings. The relationship with the child-friendly concept was analyzed by mapping the features of the medium onto the child-friendly dimensions in Indonesian Ministerial Regulation No. 8 of 2014 on child-friendly schools, the UNICEF (2009) manual, and the child-friendly learning model of Sudirjo (2010).

Results and Discussion

Trial Results and Physical Explanation

The trial results show that when the balloon attached to the bottle's mouth is squeezed, the total volume of air trapped in the system (the air inside the balloon and the air space above the water surface in the bottle) decreases. At a relatively constant temperature and an unchanged amount of air, Boyle's Law predicts that this decrease in volume increases the air pressure inside the bottle (Halliday et al., 2014). When the air pressure inside the bottle exceeds the atmospheric pressure at the hose outlet plus the hydrostatic pressure of the water column in the hose, water in the bottle is pushed and flows out through the hose into the collecting container.

Conversely, when the pressure on the balloon is released, the balloon re-expands, so the volume of air increases and the pressure inside the bottle decreases. The pressure difference between the inside of the system and the outside air is no longer sufficient to push the water, so the flow weakens and eventually stops. These findings confirm that the pressure difference between the inside and outside of the system is the primary driver of fluid flow.

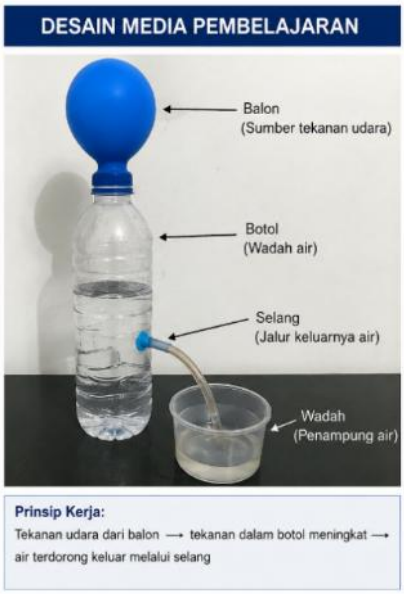

Figure 1. Design of the air-pressure water dispenser learning medium

Advantages of the Medium for Learning

Based on the trial results and the literature review, this air-pressure dispenser medium has the potential to offer six pedagogical advantages. It should be emphasized that these advantages are inferred from a qualitative demonstration and from support in previous studies, not from direct testing with students.

First, the medium makes abstract concepts concrete and provides multiple representations. Air and pressure cannot be seen, but the effects of pressure changes are clearly visible in the water flow. Students can connect action (squeezing the balloon), image (flowing water), and symbol ($P_1V_1 = P_2V_2$), which is consistent with Bruner's (1966) enactive, iconic, and symbolic representations. For children in the concrete operational stage, conceptual understanding depends on direct experience with real objects (Andesta, 2018; Marinda, 2020; Piaget & Inhelder, 1969), and cognitive ability also influences the effectiveness of learning in elementary school (Basri, 2018).

Second, the medium encourages students' active engagement. Students do not merely listen to explanations but assemble, squeeze, observe, and explain. Such interactive engagement has been associated with greater gains in conceptual understanding than traditional instruction (Hake, 1998) and is consistent with findings that specially designed media improve physics learning outcomes (Supardi et al., 2012). Peer interaction while observing and discussing also aligns with Vygotsky's (1978) view that understanding is built through social interaction.

Third, the medium is low-cost, easy to obtain, and environmentally friendly. All of its components are used items or readily available materials. This is important for equity in learning opportunities, since not all schools can provide teaching aids, especially in remote areas (Setyaningrum et al., 2018). The use of used goods has been reported as a way to overcome limited teaching aids (Fitriah et al., 2023; Nuwairah et al., 2018; Pambudi et al., 2018; Sumaryanti et al., 2021) while also producing environmentally friendly science teaching aids (Silvia & Prayogi, 2023).

Fourth, the medium is contextual. The same principle operates in gallon dispensers, water pumps, spray devices, and syringes. The closeness of an instructional medium to students' real-life context contributes to increased learning interest, which in turn positively affects learning outcomes (Tobamba et al., 2019). However, because that finding comes from social studies learning in elementary schools, its generalization to physics learning should be made with caution.

Fifth, the medium may help reduce misconceptions. Because misconceptions about pressure in closed systems are fairly common (Soeharto et al., 2019; Sholahuddin et al., 2019), the medium can be used to provoke cognitive conflict: the teacher asks students to predict what will happen if the balloon is squeezed or released, and students then observe and explain the result. Simple practicum activities have been examined as a strategy for reducing misconceptions in static fluids (Pratiwi & Wasis, 2013). Nevertheless, the effectiveness of this medium against misconceptions still needs to be demonstrated through diagnostic tests.

Sixth, the medium supports project-based learning and the development of thinking skills. Designing, assembling, and testing the medium provides a relevant PjBL experience for students and pre-service teachers alike (Sambite et al., 2019; Widyaningsih & Yusuf, 2018), and teaching aids on the topic of pressure can train science process skills (Dewi et al., 2019).

Comparison with Previous Research

Table 1. Comparison of the air-pressure dispenser medium with previous research

Study and medium	Subjects/method and main findings	Comparison with this medium
Pratiwi et al. (2022): mini dispenser from used goods (Pascal's law and	10 junior high school students; interest and motivation questionnaire; most responses	Both take the form of a dispenser from used materials. They differ in concept (Pascal and hydrostatic vs.

hydrostatic pressure)	positive.	air pressure and Boyle). Neither has quantitatively measured learning outcomes.
Nuwairah et al. (2018): teaching aid from used goods on static fluids with guided IDL model	ADDIE research and development; aid validity 70% and worksheet 79% (fairly valid); practicality 70% (good); effectiveness 0.62 (moderate); science process skills averaged 86.92% (very good).	Consistent in using used goods for fluid concepts. This medium has not yet undergone expert validation and effectiveness testing, so those stages are needed.
Pambudi et al. (2018): science teaching aids from used goods for elementary school	Developed because of limited teaching aids in elementary schools; aimed at increasing learning motivation and understanding.	Consistent in the elementary school context and use of used goods; this medium adds an option for the concept of air pressure.
Setyaningrum et al. (2018): BARBEKU on capillarity	Simple teaching aid from used goods to improve understanding; background: not all schools can provide teaching aids, especially in remote areas.	Consistent in affordability and equity; the concept addressed differs (capillarity).
Dewi et al. (2019): teaching aid on pressure for junior high school students	Trains science process skills; the aid was declared suitable for use.	Same topic (pressure); this medium highlights air pressure in a closed system and the child-friendly dimension.
Dewi Salsabila & Malik (2024): Boyle's Law practicum apparatus with a cookbook model	A structured approach facilitated accurate data collection, enhanced comprehension of gas behavior, and fostered critical thinking.	Same concept (Boyle's Law) but quantitative and instrument-based. This medium is qualitative, simple, and inexpensive; the two are complementary.
Sholahuddin et al. (2019): four-tier diagnostic test on static fluids	31 senior high school students; misconceptions of 41.94% on hydrostatic pressure and 41.94% on pressure in fluids in closed systems.	Indicates a need for media targeting pressure in closed systems, which is the target of this medium.

In general, this medium is consistent with previous studies in three respects: the use of inexpensive and used materials, an emphasis on concrete experience, and an orientation toward improving interest, motivation, and conceptual understanding. The novelty of this medium lies in (a) its focus on air pressure in a closed system as an application of Boyle's Law, whereas the mini dispenser of Pratiwi et al. (2022) focuses on Pascal's law and hydrostatic pressure; and (b) its explicit examination of the relationship with child-friendly principles. Conversely, this medium still lags behind in empirical evidence: Nuwairah et al. (2018) reported validity, practicality, effectiveness, and science process skills; Pratiwi et al. (2022) collected interest and motivation data from students; and Dewi Salsabila and Malik (2024) applied more precise data collection. Accordingly, this study is best positioned as an early design-and-build stage and a concept demonstration, not as evidence of effectiveness.

Relationship with the Concept of Child-Friendly Learning

Child-friendly learning does not merely mean an enjoyable classroom atmosphere; it concerns safety, participation, the fulfillment of rights, and suitability to children's development (Menteri Pemberdayaan Perempuan dan Perlindungan Anak Republik Indonesia, 2014; UNICEF, 2009). The protection of children within educational settings is also affirmed in Indonesia's child protection law (Republik Indonesia, 2014), and the Convention on the Rights of the Child affirms children's rights to education, play, and expressing their views (United Nations, 1989). Table 2 maps the features of the medium onto these child-friendly dimensions.

Table 2. Mapping of the medium's features onto dimensions of child-friendly learning

Child-friendly dimension	Realization in the medium	Sources
Safe and protective	Plastic and rubber materials, with no electricity, fire, or chemicals; the amount of pressure is controlled by the child's own hands.	Menteri PPPA (2014); UNICEF (2009)
Participation and learning by doing	Children assemble, squeeze, observe, predict, and explain; children are given room to express ideas and display their work.	Sudirjo (2010); Menteri PPPA (2014); United Nations (1989)
Developmentally appropriate	Abstract concepts are presented through real objects and directly observable phenomena.	Piaget & Inhelder (1969); Marinda (2020); Andesta (2018)
Enjoyable and playful	Trying and observing water flow is exploratory and may foster interest and motivation, as a similar mini dispenser received positive responses.	Pratiwi et al. (2022); United Nations (1989)
Inclusive and non-discriminatory	Inexpensive, readily available materials allow use in schools with limited resources, including remote areas.	Setyaningrum et al. (2018); Pambudi et al. (2018); UNICEF (2009)
Environmentally conscious	Uses used plastic bottles and instills the idea of reusing items.	Menteri PPPA (2014); Silvia & Prayogi (2023); Sumaryanti et al. (2021)
Respect for children's views and social interaction	Group work and discussion of observations give every child room to voice opinions.	Vygotsky (1978); United Nations (1989)

For the medium to be truly child-friendly, several safety and comfort considerations should be applied. The following are the authors' design recommendations and should be validated by experts before wider use:

- Smooth the edges of the cut bottle and the hose opening so they do not injure students' hands.
- Use non-latex balloons or make sure no student has a latex allergy, and remove balloon fragments because of the choking risk.

- Use clean water and prepare a mat and cloth to handle spills.
- Squeeze the balloon slowly and make sure the hose connection is firm so it does not detach when the pressure rises.
- Provide teacher supervision, especially for lower-grade students, and give students room to retry without fear of making mistakes.

Limitations and Directions for Further Development

This study has several limitations. First, the observations were qualitative and did not measure the magnitude of pressure or the water discharge. Second, the medium has not been tested with students, so the pedagogical advantages in Section 3.2 are potentials based on the literature, not empirical evidence from this study. Third, the height of the hose outlet relative to the water surface, the initial water volume, and the temperature were not standardized and may affect the flow. Fourth, the analysis of the relationship with the child-friendly concept is conceptual.

Further development may include (1) adding simple measuring instruments such as a manometer and a graduated measuring cup for quantitative laboratory activities at secondary and higher education levels, following the more structured Boyle's Law practicum approach (Dewi Salsabila & Malik, 2024); (2) expert validation of media and content; (3) trials with students using a pretest–posttest design and multi-tier diagnostic tests to detect misconceptions (Sholahuddin et al., 2019; Soeharto et al., 2019; Wijaya et al., 2016); (4) measurement of interest and motivation (Pratiwi et al., 2022); and (5) development of student worksheets that include safe procedures and predict–observe–explain questions.

Conclusion

The instructional medium in the form of a simple air-pressure water dispenser system is capable of concretely visualizing the relationship between air pressure and fluid flow within an enclosed space. When the balloon is squeezed, the volume of enclosed air decreases and the pressure inside the bottle increases, pushing water out through the hose in accordance with Boyle's Law; when the pressure is released, the pressure drops and the water flow weakens until it stops. Based on the trials and the literature review, the medium has the potential to be advantageous because it is concrete, encourages active engagement, is low-cost and environmentally friendly, is contextual, may help reduce misconceptions, and supports project-based learning. These advantages align with the principles of child-friendly learning: safe, participatory, developmentally appropriate, inclusive, and environmentally conscious. As an initial stage, this study should be followed by quantitative measurement, expert validation, and trials with students to demonstrate its effectiveness.

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