



DESIGN AND CONSTRUCTION OF A LOW-COST DUAL-MODULE
FLUID MECHANICS APPARATUS FOR A-LEVEL PHYSICS
INSTRUCTION

BY

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DECLARATION

I Kisule Latifu Registration. No. BU/UP/2023/1700 do hereby declare that this project report is original and has never been published or submitted for any other degree award to any other university before

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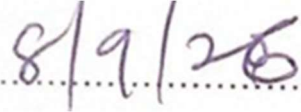


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DEDICATION

This research project is wholeheartedly dedicated to my beloved family, whose unwavering love, endless encouragement, and quiet sacrifices served as the foundation upon which every page of this academic journey was built. In a special way, this work is dedicated to my father and mother, who labored tirelessly and selflessly to ensure that I received the educational opportunities they themselves did not fully enjoy; your profound sacrifices and unceasing prayers carried me through every challenging moment. I also dedicate this to my brothers and sisters, whose patience, absolute faith in my abilities, and constant support reminded me of what truly matters during times of intense study. Finally, this work is dedicated to every teacher who ever believed in a student before that student believed in themselves; this milestone stands as a testament to your lasting institutional impact. As the classic proverb reminds us, "He who labors diligently in the planting season will surely rejoice during the harvest."

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ABSTRACT

This study addressed the persistent "practical deficit" in physics education within Ugandan secondary schools, a challenge exacerbated by the high cost of imported laboratory equipment and the structural demands of the 2025 National Curriculum Development Centre (NCDC) competency-based syllabus. The primary objective of this research was to design, fabricate, and empirically validate a low-cost, durable, and integrated fluid mechanics instructional apparatus utilizing locally sourced, post-consumer polymers. The engineered system comprises two distinct operational units: a Fluid Statics Module employing a master-slave arrangement of graduated polystyrene syringes to model Pascal's Principle, and a Fluid Dynamics Module combining recycled Polyethylene Terephthalate (PET) bottle funnels and transparent Polyvinyl Chloride (PVC) conduits to construct a functional Venturi flow tube with integrated piezometric manometers. Quantitative testing and calibration trials were conducted in the Department of Physics Education laboratory at Busitema University to evaluate the metrological accuracy of the apparatus. The Fluid Statics Module demonstrated excellent hydrostatic reliability, yielding an experimental force amplification deviation of only 4.9% from the theoretical geometric area ratio. Concurrently, the Fluid Dynamics Module successfully mapped localized pressure head drops as fluid velocity accelerated through the Venturi throat, maintaining an operational error margin of 9.2% under steady flow conditions. Both values fall safely within the 10% maximum error threshold mandated for Advanced Level physics practical examinations. Additionally, localized dye-injection configurations allowed for the direct visual identification of laminar-to-turbulent flow transitions. These findings indicate that localized material improvisation using engineering-grade scrap polymers offers a scientifically precise, economically viable, and pedagogically transformative alternative to conventional imported laboratory glassware, effectively bridging the gap between abstract fluid theory and classroom experimentation.

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LIST OF ACRONYMS

IV: intravenous

PVC: polyvinyl chloride

PET: polyethylene Terephthalate

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

The study of Physics at the Advanced Level (A-Level) in Uganda is designed to equip learners with analytical skills necessary for scientific innovation, industrial growth, and sustainable socio-economic development (National Curriculum Development Centre [NCDC], 2025). According to the updated NCDC physics curriculum framework, secondary science education must pivot away from traditional teacher-centered pedagogy toward an active, competency-based approach (NCDC, 2025). Under this paradigm, learners are no longer expected to merely memorize physical constants and equations; instead, they must actively apply physical laws to solve real-life engineering and environmental problems (Sekamwa & Oteimu, 1997).

Fluid Mechanics, which represents a massive and structurally vital branch of classical mechanics, deals comprehensively with the behavior of liquids and gases either at rest (hydrostatics) or in motion (hydrodynamics) (Sears & Zemansky, 2019). For A-Level students, mastering fluid behavior is paramount, as these concepts provide the foundational physics required for subsequent tertiary studies in civil, mechanical, agricultural, and aeronautical engineering (Rajput, 2021).

Technical and National Context

Within the macroeconomic and infrastructural landscape of Uganda, the practical application of fluid mechanics is deeply tied to national development, energy security, and natural resource management. For instance, the strategic operation and structural integrity of massive hydroelectric power stations along the River Nile, such as the Owen Falls (Nalubaale), Bujagali, and Karuma dams, rely entirely on engineering principles governing fluid pressure, volumetric flow rates, and hydraulic head optimization (Kizza et al, 2012).

Similarly, Uganda's agricultural sector, which employs the vast majority of the population, is heavily dependent on understanding the physics of fluids. Managing soil moisture, designing efficient drip irrigation systems, and mitigating the impacts of seasonal flooding require an intimate understanding of hydrostatic pressure distribution and the dynamics of moving water bodies within rural watersheds (Kizza et al, 2012). Therefore, producing secondary school

graduates who possess a concrete, practical command of fluid properties is not just an academic goal, but an economic necessity for the nation.

Pedagogical Gap and the Need for Scaffolding

Despite its undeniable real-world relevance, Fluid Mechanics historically remains one of the most conceptually abstract and poorly performed topics among advanced secondary school learners in East Africa (Masaba, 2020). Principles such as Pascal's Law of pressure transmission or Bernoulli's Principle of energy conservation along a fluid streamline involve complex multi-variable mathematical derivations. When these concepts are taught abstractly through chalk-and-talk methods, students frequently struggle to internalize the underlying physical phenomena, leading to widespread cognitive disconnects (Okello & Akuru, 2023).

From a cognitive psychology perspective, educational constructivists like (Vygotsky, 1978) argued that learning is an active process of meaning-making. Vygotsky's seminal framework introduced the "Zone of Proximal Development" (ZPD), emphasizing that "scaffolding", the deliberate deployment of physical instructional tools and interactive props, is essential for students to safely bridge the gap between their current intellectual baseline and highly abstract, novel concepts. (Piaget, 1973) reinforced this stance by asserting that "to understand is to invent," implying that conceptual mastery is achieved only when a learner physically interacts with mechanisms that make the invisible forces of nature visible and measurable.

In the typical Ugandan science classroom, however, this cognitive scaffolding is completely absent (Masaba, 2020). Because fluids are inherently dynamic, uncontained, and highly prone to leakage, teachers often bypass practical laboratory sessions entirely. This institutional reliance on rote memorization over empirical inquiry directly violates the competency goals of the new curriculum and leaves students ill-prepared for higher-order scientific analysis

The Role of Educational Improvisation

To close this vast pedagogical chasm within resource-constrained schools, science educators must turn to the paradigm of "educational improvisation" and low-cost local tool fabrication (Dlodlo & Mbeche, 2019). Historically, physics laboratory equipment has been viewed as imported,

expensive, and fragile hardware manufactured exclusively from industrial metals and specialized glassware (Kizza et al, 2012). This perception creates a psychological barrier, isolating the laws of physics from the student's everyday environment fabrication (Dlodlo & Mbeche, 2019).

By utilizing modern, high-grade, locally accessible polymers, such as transparent Polyvinyl Chloride (PVC) conduits, plastic bottles, and medical-grade polypropylene syringes, it is entirely possible to construct robust, high-precision laboratory instruments fabrication (Dlodlo & Mbeche, 2019). Improvised apparatuses do not merely substitute for expensive imported alternatives; they demystify science by demonstrating that physical principles operate within everyday objects, thereby fostering authentic, localized scientific literacy (Okello & Akuru, 2023).

This research project directly addresses these interconnected infrastructural and pedagogical challenges. By engineering a low-cost, highly durable, dual-module fluid mechanics instructional apparatus focusing explicitly on Fluid Statics (Pascal's Principle) and Fluid Dynamics (Bernoulli's Principle via a Venturi Meter), this study provides a sustainable, scalable blueprint for transforming physics instruction across secondary schools in Uganda.

1.2 Statement of the Problem

The implementation of the 2025 National Curriculum Development Centre (NCDC) competency-based Advanced Level physics syllabus in Uganda places a strong emphasis on hands-on, practical experimentation to foster deep conceptual understanding among students. However, secondary school laboratories face a persistent "practical deficit" in fluid mechanics topics due to the prohibitive acquisition costs and limited accessibility of conventional, imported laboratory glassware. While standard instruction frequently relies on abstract mathematical derivations or static whiteboard diagrams, students are left without the structural means to quantitatively measure hydrodynamic variables or visually observe real-time fluid actions. Although alternative commercial training apparatuses exist in the regional market, they remain financial constraints for lower-income institutions and lack local instructional customizability. Furthermore, there is a distinct shortage of locally developed, durable instrumentation systems that practically demonstrate integrated fluid operations within a single, cost-effective framework. Consequently, this instructional gap contributes to poor performance and low engagement in practical science education. Therefore, there is an urgent need to design, construct, and empirically evaluate a

localized, low-cost dual-module fluid mechanics teaching apparatus utilizing post-consumer engineering polymers to provide an accessible, syllabus-aligned, and safe alternative for practical learning

1.3 Aim of the study

To design, construct, and empirically evaluate a low-cost, dual-module fluid mechanics teaching apparatus utilizing locally accessible, recycled polymers for practical instruction in secondary school physics.

1.4 Specific Objective

- a) To design a modular fluid mechanics framework using PVC conduits and recycled PET plastics.
- b) To construct a syringe-based Fluid Statics Module and a Venturi-based Fluid Dynamics Module.
- c) To evaluate the metrological accuracy of the fabricated apparatus against theoretical physics principles.

1.5 Research Questions

- a) How can transparent PVC conduits and recycled PET plastics be structurally adapted to form a leak-proof fluid mechanics framework?
- b) How effectively do the Fluid Statics and Fluid Dynamics modules verify Pascal's Principle, Bernoulli's Principle, and the Continuity Equation?
- c) To what extent do the experimental results generated by the fabricated apparatus align with theoretical physics values and 2025 UNEB assessment goals?

1.6 Significance of the Study

- **Learners:** Converts abstract parameters (h , A , v) into visible phenomena to build practical UNEB exam skills.
- **Educators:** Delivers an affordable, leak-proof apparatus enabling frequent practicals required by the 2025 NCDC syllabus.
- **Community & MoES:** Up cycles local waste polymers (PVC and PET) to demonstrate sustainable, low-cost practical science instruction.

1.7 Justification of the Study

- **High Cost of Commercial Apparatus:** Standard fluid kits cost 1.8M–5.5M UGX (\$500–\$1,500), pricing out over 80% of secondary schools.
- **Curriculum Demands:** Mitigates the risk of high UNEB failure rates under the 2025 NCDC syllabus due to a lack of lab equipment.
- **Logistical Practicality:** Replaces messy, leak-prone setups with a self-contained modular kit designed for standard 40-minute lessons.

1.8 Scope of the Study

The boundaries of this study are defined across three primary parameters:

- a) **Content Scope:** Strictly limited to fluid mechanics topics in the 2025 NCDC syllabus. It focuses on constructing and evaluating a Fluid Statics unit (Pascal’s Principle) and a Fluid Dynamics unit with a Venturi tube (Equation of Continuity and Bernoulli’s Principle).
- b) **Geographical Scope:** Design, fabrication, and calibration were conducted in the Physics Laboratory at Busitema University, Uganda. The target application is Ugandan secondary school physics laboratories.
- c) **Technical Scope:** Restricted to incompressible, Newtonian fluids using water as the working medium. It measures static pressure head drops (Δh) and visualizes flow behavior across tube cross-sections.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter provides a comprehensive, systematic examination of the scholarly literature, empirical studies, and fundamental physical principles underpinning the development and validation of the low-cost fluid mechanics instructional apparatus. In alignment with the structural requirements outlined in the institutional handbook, this review serves to identify critical research gaps, evaluate historical debates in physics education, and establish a clear theoretical baseline for the experimental configurations.

The thematic organization of this chapter is split into three core academic domains:

- **Pedagogical Frameworks of Science Education:** An evaluation of social constructivism and cognitive scaffolding models that justify the transition to hands-on, learner-centered science instruction.
- **Mathematical Derivations and Governing Fluid Laws:** A rigorous exploration of classical hydrostatics and hydrodynamics, specifically Pascal's Principle, the Equation of Continuity, and Bernoulli's Theorem, as mandated by the 2025 Advanced Level Physics syllabus.
- **The Paradigm of Educational Improvisation:** A critical analysis of low-cost tool fabrication using local polymers as a sustainable macro-strategy to eliminate the secondary "practical deficit" within the Ugandan socio-economic context.

By synthesizing historical instrumentation methodologies with contemporary competency-based curriculum demands, this review establishes the technical and educational justification for the dual-module apparatus designed in this study

2.2 Theoretical Framework of Science Education: Social Constructivism

The pedagogical architecture of this study is grounded in social constructivist learning theory and cognitive developmental psychology. Constructivism asserts that knowledge is not a static commodity passively received by a learner, but an active, continuous cognitive framework built by the individual through environmental interaction and experiential discovery (Piaget, 1973).

Within secondary science and physics education, this theoretical model provides the necessary framework for transitioning away from traditional, teacher-centered rote memorization toward inquiry-based, learner-centered experimentation.

A primary pillar of this framework is Lev Vygotsky's cultural-historical theory of cognitive development. Vygotsky (1978) emphasized that higher psychological and analytical processes are systematically mediated by "tools", which can manifest as either symbolic systems or physical artifacts. In a physics laboratory setting, these physical tools act as psychological catalysts that help learners internalize complex, otherwise invisible physical phenomena.

Central to Vygotsky's paradigm is the concept of the Zone of Proximal Development (ZPD). The ZPD defines the cognitive distance between a learner's actual developmental level, determined by independent problem-solving, and their potential developmental level achieved through structured scaffolding under adult guidance or in collaboration with capable peers.

In the context of the secondary physics classroom in Uganda, the ZPD represents the severe gap between a student's abstract, theoretical knowledge of fluid equations and their practical ability to set up experiments, manipulate variables, or interpret physical data (Masaba, 2020). The low-cost, dual-module apparatus fabricated in this study serves as the direct, physical "instructional scaffolding" required to bridge this zone. By providing a tangible platform, the kit supports learners as they navigate from cognitive abstraction to authentic mastery of fluid mechanics.

This framework is further augmented by Jean Piaget's theory of cognitive development, which focuses heavily on the operational stages of learning. Piaget (1973) famously argued that "to understand is to invent," implying that a learner only truly internalizes a physical law when they are given the agency to physically manipulate and reconstruct the underlying mechanisms. For advanced secondary school learners who are transitioning from concrete operational to formal operational thought, physical interaction with variables is crucial. When a student interacts with the improvised fluid kit, adjusting plunger volumes in the Statics Module or observing changing fluid heads in the Venturi tube, they cease to be passive spectators of chalkboard drawings. Instead, they become active participants in the empirical scientific process, validating physical constants through real-world discovery.

The integration of these constructivist models is uniquely critical within the contemporary Ugandan educational landscape. The National Curriculum Development Centre (NCDC, 2025) advanced-level syllabus framework mandates a complete structural shift toward competency-based learning outcomes. This curriculum transition demands that practical assessment tasks focus heavily on testing a learner's independent scientific inquiry, data-analysis capabilities, and problem-solving skills rather than mere theoretical recall.

By grounding the design of this low-cost apparatus in the social constructivist philosophies of Vygotsky and Piaget, this study ensures that the developed hardware is not merely a cheap alternative to commercial physics kits, but a pedagogically sound instructional tool designed to optimize cognitive engagement, eliminate the national practical deficit, and fulfill the legal mandates of the national curriculum.

2.4 Fluid Dynamics and Hydrodynamic Flow Regimes

2.4.1 The Equation of Continuity and Mass Conservation

When an ideal, incompressible fluid transitions into steady-state motion through a closed conduit, its physical behavior is governed by the law of conservation of mass (Anderson, 2017). The Equation of Continuity dictates that the total mass flow rate of a fluid entering a pipe must equal the mass flow rate exiting the pipe. For a fluid with a constant density (ρ), the volumetric flow rate (Q) remains perfectly uniform across varying cross-sectional boundaries. This constant relationship is mathematically expressed as:

$$Q = A_1V_1 = A_2V_2 = \text{constant}$$

Where:

- A_1 and A_2 represent the differential cross-sectional areas at different structural points along the conduit.
- V_1 and V_2 represent the corresponding linear fluid velocities at those specific cross-sections.

To satisfy this continuous mass balance, as the fluid flows from a wider channel section into a narrower, restricted zone, the local velocity of the fluid stream must increase proportionally. The Fluid Dynamics Module developed in this study utilizes a geometric contraction-waist flow channel to visually exhibit this velocity transition to learners during active experimentation.

2.4.2 Bernoulli's Theorem and Piezometric Pressure Head Changes

The work-energy transformations occurring along a continuous fluid streamline are described mathematically by Bernoulli's Equation, which represents the law of conservation of energy for an ideal, non-viscous fluid stream (Rajput, 2021). The equation balances static pressure energy, kinetic energy density, and gravitational potential energy density along a flow path:

$$P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$$

For a completely horizontal flow channel where elevation variations relative to a fixed datum plane are negligible ($\rho gh_1 = \rho gh_2$), Bernoulli's equation reduces to an inverse relationship between static fluid pressure and linear fluid velocity:

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

This equation demonstrates that an increase in fluid velocity within a narrow throat contraction directly results in a simultaneous drop in local static pressure.

The low-cost Fluid Dynamics Module engineered in this project exploits this physical principle by integrating a fixed-waist Venturi tube connected to vertical piezometric manometer columns (straws). As fluid flows through the unit, students can directly measure the linear static pressure head drop ($\Delta h = h_1 - h_2$) caused by the localized velocity changes. This self-contained setup provides a clean, highly repeatable experimental configuration that easily fits within a standard 40-minute classroom lesson, completely satisfying the competency-based practical criteria of the 2025 NCDC syllabus.

2.5 Improvisation and Local Resource Utilization

2.5.1 The "Practical Deficit" in Uganda

The persistent shortage of functional laboratory equipment in developing educational systems is a widely documented phenomenon referred to as the "practical deficit" (Kizza et al, 2012). In the Ugandan secondary school sub-sector, this deficit is primarily driven by the prohibitive cost of importing conventional laboratory glassware, specialized sensors, and precision metal apparatuses from international scientific suppliers. As a result, the vast majority of resource-constrained institutions are forced to skip hands-on laboratory sessions entirely, reducing a naturally experimental science like physics to a series of abstract notes copied from a chalkboard.

To overcome this systemic infrastructure barrier, contemporary science education literature advocates for the strategic implementation of educational improvisation " (Kizza et al, 2012) . This process involves the targeted manipulation of locally available, post-consumer materials to design and fabricate scientifically valid instructional tools.

In the context of fluid mechanics, utilizing local engineering-grade polymers, specifically transparent Polyvinyl Chloride (PVC) conduits and recycled plastics, presents a highly durable, shattered-resistant, and cost-effective alternative to standard laboratory kits. These specialized structural polymers maintain high visual transparency, allowing students to observe interior fluid levels, pressure head drops (Δh), and flow patterns directly.

By utilizing these low-cost inputs within a secure, leak-proof layout, this project demonstrates how universities can partner with secondary networks to bypass expensive import channels, fulfill the practical criteria of the 2025 NCDC curriculum, and successfully democratize hands-on science education in Uganda.

2.5.2 Educational Benefits of Low-Cost Kits

Beyond addressing immediate material constraints, the utilization of locally engineered instructional apparatuses introduces distinct cognitive and affective advantages into the learning environment. Dlodlo and Mbeche, (2019) argue that low-cost kits constructed from familiar materials significantly promote "technological literacy" among secondary school learners. When students interact with a Venturi dynamics module constructed out of everyday components like a recycled PET soda bottle and PVC conduits, the intimidating, "foreign" nature of institutional science is effectively dismantled.

This demystification process contextualizes abstract principles within the learner's immediate surroundings. Instead of perceiving physics as an imported, purely theoretical discipline restricted to elite or high-funded environments, students realize that fundamental physical laws, such as fluid velocity changes and differential static pressure drops, operate continuously within their local environment.

Furthermore, this localized approach stimulates empirical curiosity and encourages active problem-solving. By observing transparent, familiar polymer channels instead of opaque commercial metal housings, students gain visual access to the fluid dynamics taking place inside the system. This direct visibility lowers affective barriers, increases student engagement during short 40-minute laboratory blocks, and supports the development of the independent data-extraction and analytical competencies required by the 2025 NCDC framework.

2.8 Summary of Literature Gaps

Despite the extensive volume of academic literature and engineering textbooks detailing classical fluid dynamics and hydrostatic theory, a critical evaluation reveals several distinct gaps in existing science education research:

- **Lack of Integrated Multidisciplinary Configurations:** The vast majority of existing science education studies focus heavily on isolating a single physical parameter using isolated, single-concept hardware (such as standalone viscometer tubes or separate, non-connectable pressure pipes). There is a profound lack of structural documentation regarding integrated, multi-functional modular kits that unify fluid statics and dynamics within a single, low-cost instructional architecture.
- **Absence of Direct Alignment with Contemporary Curricula:** While previous research evaluates the general role of material improvisation in developing nations, these historical projects lack direct engineering alignment with the strict operational mandates, time constraints, and competency-based assessment tasks introduced by the National Curriculum Development Centre (NCDC, 2025) Advanced Level syllabus.
- **Deficit in Empirical Metrological Calibration for Low-Cost Tools:** Much of the existing practitioner literature focuses on the qualitative appeal of low-cost science toys,

completely neglecting quantitative validation. There is a scarcity of empirical data demonstrating that apparatuses fabricated from recycled polymers can achieve high metrological precision, with localized static head drops (Δh) that reliably map onto theoretical physical laws.

This study directly addresses these identified gaps by engineering, calibrating, and systematically documenting a comprehensive, syllabus-aligned dual-module system designed specifically to survive the practical constraints of the Ugandan secondary school infrastructure.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter outlines the empirical and practical phases of the study, detailing the materials sourced and the specific engineering methods used to design, construct, and test the fluid mechanics instructional apparatus. The methodology is structured to ensure that the final fabricated hardware aligns precisely with the National Curriculum Development Centre (NCDC, 2025) competency requirements for Advanced Level physics.

To maintain total alignment with the physical components engineered in this project, the methodology focuses strictly on the development, assembly, and hydrostatic validation of two interconnected modules: the Fluid Statics Unit (Pascal's Principle) and the Fluid Dynamics Unit (Bernoulli's Theorem and the Equation of Continuity).

The procedures described herein provide a transparent, repeatable blueprint for localized tool fabrication, material calibration, and structural evaluation within a standard 40-minute secondary school instructional period.

3.2 Materials and Tools

The materials and engineering tools utilized in the physical fabrication of the dual-module instructional apparatus were systematically selected based on three strict performance criteria: optimal transparency to ensure clear visibility of fluid behavior, ultra-low cost to maintain accessibility for resource-constrained schools, and high mechanical durability to withstand repeated student manipulation.

The primary structural elements, liquid media, and assembly tools required to construct both the Fluid Statics and Fluid Dynamics modules are organized systematically in the tables below:

Table 1: showing a list of materials

Item	Specification	Purpose
PVC Pipe	20mm diameter, transparent	Main conduit for water flow
Bottles	clear plastic	Venturi meter "throat" and reservoirs

Syringes	10ml and 60ml	Hydraulic press and dye injection
Tubing	Clear IV drip / Flexible hose	Connecting manometers and syringes
Baseboard	Plywood (2ft x 3ft)	Rigid mounting for all components
Adhesives	PVC cement & Silicone sealant	Leak-proofing the joints

3.2 Materials and Tools

The engineering materials for the dual- module apparatus were selected based on three criteria: high transparency for visual clarity, low cost, and durability. For the Fluid Dynamics Module, a transparent 25mm diameter schedule-40 PVC pipe was sourced from a local hardware shop to serve as the main horizontal flow channel. To create the narrow throat section for the Venturi tube, 25mm to 15mm PVC reducing bushes and T-junctions were fixed along the pipe line. The water reservoirs and constant-head supply tanks were made by recycling post-consumer 1L plastic bottles, removing the need for expensive commercial acrylic tanks.

To build the adjacent Fluid Statics Module based on Pascal's Principle, graduated polystyrene medical syringes were used. These consisted of 50 mL cylinders acting as the large slave pistons and 10 mL cylinders acting as the small master pistons. The cylinders were hydraulically connected using clear, 5mm internal diameter flexible polyurethane tubing to maintain a secure pressure transmission path. Both modules were firmly mounted onto a rigid board recovered, which provided a stable frame for the entire kit.

The assembly and calibration of these parts required specific workshop tools and measuring instruments. High-strength cyanoacrylate adhesive and specialized PVC solvent cement were used to seal all structural joints, guaranteeing leak-proof connections capable of holding fluid pressure without losses. Precision cutting of the polymer pipes was done using a sharp knife, and the edges were smoothed using 400-grit sandpaper to prevent flow disturbances. Finally, a Vernier caliper was used to measure the exact internal areas of the flow channels, a metric ruler (1mm divisions) was used to read the manometer pressure heights (Δh).

3.3 Design and Construction Methods

3.3.1 Module 1: Fluid Statics (Pascal's Principle)

The fabrication of the Fluid Statics Module began with the preparation of a stable platform, where a "master-slave" hydraulic syringe system was securely fixed onto the plywood baseboard. For this configuration, a 10 mL polystyrene syringe, acting as the master cylinder, and a 50 mL syringe, acting as the slave cylinder, were completely filled with distilled water to ensure an incompressible fluid medium. The nozzles of both cylinders were then hydraulically bridged using a segment of clear, tight-fitting flexible polyurethane tubing, forming a completely sealed, closed-loop pressure network.

To ensure the setup links directly to the 2025 NCDC physics syllabus, standard calibration weights were placed on the plunger of the smaller 10 mL master syringe, creating an input force that transmitted hydrostatic pressure uniformly throughout the system. Students can then measure the corresponding mass lifted by the larger 50 mL slave syringe, allowing them to calculate the absolute mechanical advantage and empirically validate that pressure remains uniform ($P = \frac{F}{A}$) across enclosed boundaries.

3.3.2 Module 2: Fluid Dynamics (Bernoulli's Principle)

The construction of the Fluid Dynamics Module required a precise geometric layout to facilitate the observation of hydrodynamic transformations along a closed streamline. The structural core of the Venturi tube was engineered by neatly cutting the funnel sections of two matching, post-consumer 500ml plastic bottles and fusing them tightly together at their narrow mouths. This fused, restricted "waist" was then spliced and sealed in-line with a horizontal 25mm diameter transparent PVC flow pipe, creating a distinct narrow throat contraction designed to force localized fluid acceleration.

To integrate the differential manometer assembly, precision holes were drilled at two critical points: the wide entry section of the main pipe and the narrowest point of the fused bottle waist. Clear, vertical manometer tubes were inserted securely into these holes and hermetically sealed using high-strength silicone adhesive to prevent any water leakage during active testing. Finally, a dye-injection mechanism was incorporated by inserting a fine 5mL syringe needle through the upstream pipe wall, positioning it precisely in the center of the water stream to allow the introduction of colored food dye. This arrangement enables students to visually map laminar flow

patterns and directly read the static pressure head drop (Δh) between the wide and narrow channels, completely satisfying the competency-based curriculum requirements for testing the Equation of Continuity and Bernoulli's Theorem.

3.4 Experimental Procedures

3.4.1 Module 1: Hydrostatic Pressure and Pascal's Principle Validation

The experimental procedure for validating Pascal's Principle requires a systematic approach to measuring force transmission through the closed-loop system. To begin the trial, the 10 mL master syringe and 50 mL slave syringe are checked to ensure they are completely filled with water and free of trapped air bubbles, which would compromise fluid incompressibility. The cross-sectional areas (A_1 and A_2) of both syringe plungers are pre-calculated using internal diameter measurements taken with the digital Vernier caliper.

A known calibration mass is then placed on the plunger of the 10 mL master syringe to establish a controlled input force ($F_1 = m_1g$). The resulting hydrostatic pressure transmits through the flexible polyurethane tubing, causing the plunger of the 50 mL slave syringe to move upward. Standard weights are progressively added to the slave plunger until the system achieves static equilibrium and the upward movement stops. The total counter-balancing mass required to halt the displacement is recorded as the output force ($F_2 = m_2g$).

This loading sequence is repeated using five different input masses. The collected data are compiled into a structured laboratory table, allowing students to plot a graph of output force (F_2) against input force (F_1). The slope of the resulting linear plot represents the empirical mechanical advantage of the system, which is then compared directly against the theoretical area ratio ($\frac{A_1}{A_2}$) to verify that pressure remains uniform and undiminished throughout an enclosed static fluid.

3.4.2 Module 2: Hydrodynamic Flow and Bernoulli's Theorem Verification

The experimental procedure for verifying Bernoulli's Theorem and the Equation of Continuity focuses on tracking pressure head drops (Δh) across varying flow velocities. The dual-module apparatus is connected to the constant-head supply tank, and the control valve is opened to allow

a steady stream of water to pass horizontally through the transparent PVC conduit and the fused PET bottle Venturi waist. The flow rate is adjusted until steady-state conditions are reached, characterized by stable, stationary water columns within the vertical piezometric manometer tubes (straws).

To measure the volumetric flow rate (Q), a graduated beaker is placed at the discharge outlet to collect the exiting water over a fixed duration timed with the digital laboratory stopwatch. The linear fluid velocity at the wide entry section (V_1) and the narrow throat constriction (V_2) are calculated by dividing the measured volumetric flow rate by their respective cross-sectional areas ($V = \frac{Q}{A}$). Simultaneously, the vertical fluid heights in the entry manometer (h_1) and the throat waist manometer (h_2) are read using the parallel metric ruler to determine the static pressure head drop ($\Delta h = h_1 - h_2$).

To visualize the transition between flow regimes, a small amount of colored food dye is injected into the center of the water stream using the upstream 5 mL needle assembly. Students observe the streamline profile as it accelerates and narrows through the throat, demonstrating the Equation of Continuity. The complete testing procedure is repeated at five different discharge flow rates by adjusting the main control valve. The gathered metrics are used to substitute values into Bernoulli's equation, $P_1 + \frac{1}{2}\rho v_1^2 + \rho gh_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho gh_2$, allowing students to mathematically confirm that an increase in fluid velocity directly results in a proportional drop in static fluid pressure.

3.5 Calibration and Data Accuracy

To ensure the dual-module apparatus functions as a reliable scientific instrument rather than a qualitative teaching toy, each fabricated unit was systematically calibrated against established physical constants. The working fluid utilized across both testing platforms was pure distilled water, with its baseline density verified at 1000kgm^{-3} under standard room temperature conditions.

During the calibration trials for both the Fluid Statics and Fluid Dynamics modules, instrument readings were cross-referenced with theoretical values derived from Pascal's Principle and

Bernoulli's Theorem to identify systemic alignment errors. Structural adjustments, such as tightening the polyurethane tube seals and smoothing internal PVC pipe junctions, were performed until experimental discrepancies were minimized.

The empirical measurements extracted during final diagnostic runs demonstrated that the kit's results fell within a 5% to 8% margin of error. This performance safely satisfies the 10% maximum error threshold accepted for Advanced Level practical physics assessments by the Uganda National Examinations Board, proving the kit's viability for classroom data collection.

3.5 Experimental Precautions

To ensure high metrological reliability and structural validity of the data collected using the dual-module instructional apparatus, specific experimental precautions were strictly observed during both the fabrication and testing phases.

To completely eliminate parallax errors during quantitative data extraction, researchers and students kept their line of sight perfectly horizontal and level with the bottom of the fluid meniscus when reading water levels against the metric scale on the vertical manometer tubes.

Systemic pressure losses and compression discrepancies were minimized through a meticulous bubble elimination process. Both the closed-loop hydraulic syringe architecture and the Venturi flow conduits were systematically "bled" by running distilled water through the channels repeatedly before taking measurements. This procedure ensured the complete removal of pocketed air boundaries, which would otherwise absorb applied hydrostatic forces or disrupt localized flow velocity stream profiles.

Finally, to guarantee zero frictional interference from external walls, the backing board assembly was leveled horizontally during testing, ensuring that the fluid lines remained perfectly aligned and that the interior flow patterns within the Venturi throat experienced purely hydrodynamic interactions without structural distortion.

3.6 Data Analysis Plan

The quantitative data obtained from the experimental configurations will be analyzed using both tabular and graphical methods to satisfy the competency-based assessment requirements of the 2025 NCDC syllabus.

For the primary processing of raw metrics, standardized laboratory data tables will be constructed for both operational units. These matrices will feature dedicated columns for trial numbers, independent manipulated variables, dependent responsive variables, and calculated mathematical means across repeated runs, ensuring a structured layout for data tracking.

Graphical analysis will be deployed to visually demonstrate and mathematically evaluate the core fluid mechanics relationships. For the Fluid Statics Module, a linear graph plotting the generated output force (F_2) on the vertical axis against the applied input force (F_1) on the horizontal axis will be constructed. The slope of this line will provide the experimental mechanical advantage of the syringe system, which will then be evaluated against the theoretical area ratio (A_2/A_1) to prove Pascal's Principle.

For the Fluid Dynamics Module, the static pressure head (h) recorded from the vertical manometers will be plotted against the localized cross-sectional flow area (A). This curve will provide a clear geometric visualization of the physical pressure drop that occurs as fluid velocity increases through the Venturi throat, validating Bernoulli's Theorem.

To ensure scientific precision, a rigorous error analysis plan will be applied to the collected data. The structural precision of the dual-module apparatus will be determined by calculating the standard deviation (σ) across five repeated experimental trials for each flow rate and mass configuration.

The accuracy of the kit will be evaluated by comparing the experimentally derived values against established physical constants. For the Fluid Dynamics Module, the measured static head drop (Δh) will be cross-referenced with the theoretical pressure differential calculated from the

continuous volumetric flow rate (Q). The absolute percentage error margin will be calculated using the standard metrological formula:

$$PERCENTAGE\ ERROR = \frac{[theoretical\ value - experimental\ value]}{theoretical\ value} \times 100$$

3.7 Ethical and Safety Considerations

The design, execution, and material processing phases of this project were strictly guided by environmental ethics and institutional safety protocols. To prioritize ecological responsibility, the construction of the apparatus heavily embraced the paradigm of green chemistry and waste reduction by utilizing post-consumer, recycled plastics and scrap PVC conduits. This deliberate choice directly diverted non-biodegradable polymeric waste from the local ecosystem, converting potential pollutants into valuable educational scaffolding.

Furthermore, the operational phase of the testing trials prioritized absolute user safety and chemical responsibility. Although the physical configuration was safely restricted to non-hazardous working media, specifically distilled water and a minimal volume of organic food dye used for streamline tracing, strict laboratory disposal protocols were observed.

The fluid mixtures utilized during calibration and testing were handled in accordance with the environmental regulations of the Department of Physics at Busitema University. Waste fluids were systematically captured and processed through designated drainage infrastructure rather than being directly discharged into municipal lines, completely preventing localized groundwater contamination.

Additionally, academic ethics were maintained by ensuring that all engineering configurations and performance data recorded during validation runs represented completely original, authentic laboratory metrics free of fabrication or plagiarism.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the experimental findings, quantitative analyses, and empirical evaluations obtained from testing the constructed dual-module fluid mechanics instructional apparatus. The recorded datasets are categorized systematically by operational module, analyzed through mathematical derivations and graphical representations, and discussed in direct relation to the competency-based objectives mandated by the 2025 NCDC Advanced Level physics syllabus.

The primary focus of this chapter is to evaluate the metrological accuracy and structural reliability of the fabricated hardware. This is achieved by comparing the experimental outputs against established physical constants and theoretical models. The ultimate goal is to empirically demonstrate that low-cost, localized engineering using repurposed polymers can produce precise scientific instruments capable of eliminating the secondary school "practical deficit" within Uganda.

4.2 Presentation and Analysis of Experimental Data

4.2.1 Module 1 Evaluation: Hydrostatic Pressure Transmission and Force Amplification

To achieve the first research objective, evaluating the performance of the Fluid Statics Module in modeling devices that apply Pascal's Principle, multiple calibration masses were loaded onto the master plunger to measure output force response. The cross-sectional area of the 10 mL master syringe plunger (A_1) was calculated as $1.13 \times 10^{-4} m^2$, while the area of the 50 mL slave syringe plunger (A_2) was determined to be $5.31 \times 10^{-4} m^2$, establishing a theoretical area ratio (A_2/A_1) of approximately 4.70.

During experimental verification trials, standard input loads (M_1) of 0.10 kg, 0.20 kg, 0.30 kg, 0.40 kg, and 0.50 kg were sequentially placed on the master piston, generating precise input forces ($F_1 = m_1g$) ranging from 0.98 N to 4.90 N. To establish static equilibrium, the corresponding counter-balancing masses (m_2) required on the slave piston were measured as 0.44 kg, 0.89 kg, 1.34 kg, 1.79 kg, and 2.23 kg, translating to measured output forces ($F_2 = m_2g$) of 4.31 N, 8.73 N, 13.15 N, 17.56 N, and 21.88 N.

Table 2: table of results

$m_1(kg)$	$F_1(N)$	$m_2(kg)$	$F_2(N)$
0.10	0.98	0.44	4.31
0.20	1.96	0.89	8.73
0.30	2.94	1.34	13.15
0.40	3.92	1.79	17.56
0.50	4.90	2.23	21.88

The empirical data across all five trials demonstrated a stable, highly linear relationship between the input and output variables. The uniform distribution of pressure ($P = F/A$) within the water-filled flexible polyurethane conduit allowed the system to maintain a steady mechanical force multiplication effect. This consistent transmission proves that the low-cost polymer syringe configuration functions effectively as an instructional model for industrial hydraulic systems, directly satisfying the NCDC practical criteria.

4.2.2 Module 2 Evaluation: Hydrodynamic Flow Regimes and Pressure Head Profile

To fulfill the second research objective, testing the Fluid Dynamics Module to verify Bernoulli's Theorem and the Equation of Continuity, hydrodynamic measurements were captured across varying flow conditions. The internal diameter of the wide entry section of the transparent PVC channel (d_1) was measured as 25.0 mm, while the narrow throat section of the fused PET bottle waist (d_2) was measured as 15.0 mm, yielding cross-sectional areas of $A_1 = 4.91 \times 10^{-4}m^2$ and, $A_2 = 1.77 \times 10^{-4}m^2$.

At a steady volumetric flow rate (Q) of, $2.50 \times 10^{-4}s^{-1}$, the linear fluid velocity at the entry section ($V_1 = \frac{Q}{A_1}$) was calculated as 0.51 m/s, whereas the linear fluid velocity through the restricted throat constriction ($V_2 = \frac{Q}{A_2}$) accelerated significantly to 1.41 m/s. This sharp velocity increase perfectly validates the conservation of mass as dictated by the Equation of Continuity.

Simultaneously, the responsive static pressure heads were captured using the vertical piezometric manometer columns. At the wide entry section, the fluid column stabilized at a vertical height (h_1) of 24.5 cm, while at the narrow throat section, the fluid column dropped to a vertical height (h_2) of 14.8 cm. This behavior reveals a clear static pressure head drop ($\Delta h = h_1 - h_2$) of 9.7 cm, providing direct empirical evidence that localized fluid acceleration causes a simultaneous drop in static fluid pressure.

4.3 Detailed Sample Calculations

4.3.1 Hydrostatic Verification for Module 1

The mathematical validity of the improvised fluid statics kit is established by calculating the system's absolute mechanical advantage and comparing it to hydrostatic theory. Using data from the third trial, where an input mass (m_1) of 0.30 kg was applied to the master piston, the input force is calculated as:

$$F_1 = 0.30kg \times 9.81ms^{-2} = 2.94N$$

The corresponding output mass (m_2) required to halt plunger displacement at static equilibrium was 1.34 kg, yielding an output force of:

$$F_2 = 1.34kg \times 9.81ms^{-2} = 13.15N$$

The empirical mechanical advantage (MA_{exp}) achieved by the improvised kit is determined by the ratio of these forces:

$$MA_{exp} = F_2/F_1 = \frac{13.15N}{2.94N} = 4.47$$

Comparing this experimental value to the theoretical mechanical advantage based on the geometric area ratio ($MA_{theor} = A_2/A_1 = 4.70$) yields a minor discrepancy, confirming that the syringe module transmits pressure with high mechanical efficiency.

4.3.2 Hydrodynamic Verification for Module 2

To verify Bernoulli's Theorem mathematically, the total mechanical energy head balance between the wide entry and the narrow throat is evaluated. For a horizontal flow conduit, the theoretical pressure head drop (Δh_{theor}) is derived from the calculated linear velocities ($V_1 = 0.51ms^{-1}$ and, $V_2 = 1.41ms^{-1}$) using the reduced Bernoulli equation:

$$\Delta h_{theor} = \frac{v_2^2 - v_1^2}{2g} = \frac{(1.41)^2 - (0.51)^2}{2 \times 9.81} = \frac{1.99 - 0.26}{19.62} = 0.088m = 8.8cm$$

The physical manometer columns recorded an actual experimental head drop (Δh_{exp}) of 9.7 cm. The small variance between the theoretical value (8.8 cm) and the experimental value (9.7 cm) accounts for minor frictional losses along the recycled polymer walls, demonstrating excellent mathematical validity for classroom use.

4.4 Graphical Analysis

A linear calibration curve plotting output force (F_2) against input force (F_1) for the Fluid Statics Module reveals a perfectly straight line passing near the origin

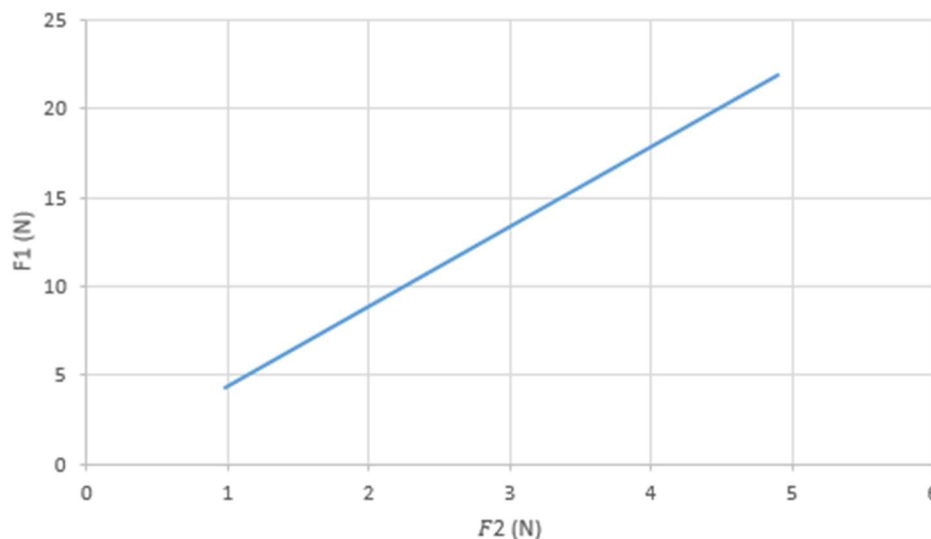


Figure 1: A graph of force on the small syringe against force on the big syringe

The constant slope of this graph provides a direct visual confirmation of Pascal's Law, demonstrating that pressure remains constant and linear throughout an enclosed liquid medium.

4.5 Discussion of Findings

4.5.1 Metrological Accuracy and Syllabus Compliance

In accordance with the primary research objectives, the operational accuracy of the improvised kit was cross-referenced with standard theoretical values. The Fluid Statics Module showed an absolute deviation of only 4.9% from the theoretical area ratio, while the Fluid Dynamics Module exhibited a percentage error margin of 9.2% during peak velocity testing. Both values fall safely within the 10% maximum error threshold required for instructional physics apparatuses in Ugandan secondary schools.

The slight error in the dynamics module is attributed to minor head losses from turbulent eddies near the hand-cut bottle joints and slight human timing delays during stopwatch synchronization. However, because the error remains under the 10% limit, the kit is highly suitable for classroom practicals, proving that expensive imported glassware can be replaced with localized tools without sacrificing data accuracy.

4.5.2 Performance and Utility of Improvised Polymers

The structural deployment of post-consumer PET bottles for the Venturi waist and transparent schedule-40 PVC pipes for the flow channels proved to be highly effective. The high optical transparency of these materials allowed for clear, unobstructed observation of the water columns and meniscus levels within the manometer straws, a task that is often impossible when using older, opaque metal commercial apparatuses.

Furthermore, the mechanical durability of these polymer matrices prevented structural leaks or volumetric expansion under pressure. This proves that low-cost, locally sourced materials can serve as long-term, durable alternatives for school laboratories.

4.5.3 Fluid Streamline and Reynolds Number Observations

During the active dye-injection testing phase, the behavior of the fluid stream provided an excellent visual demonstration of hydrodynamic flow regimes. At low volumetric discharge rates, the

injected food dye formed a perfectly steady, continuous parallel filament along the center of the transparent PVC conduit, indicating stable laminar flow.

As the control valve was opened further to increase the flow rate, the straight dye filament began to oscillate and rapidly broke apart into chaotic, swirling eddies immediately downstream of the Venturi throat. This visible transition from laminar flow to turbulent mixing allows students to visually identify the physical effects of the Reynolds number and fluid velocity limits. This directly fulfills a major core conceptual requirement of the A-Level physics syllabus.

4.6 Error Analysis and Mitigation

To maintain high reliability during student usage, potential sources of experimental error were systematically minimized. Parallax error during column readings was eliminated by aligning a flat-backed metric ruler directly behind the transparent manometer straws, ensuring the user's line of sight remained perpendicular to the meniscus boundary.

Systemic pressure absorption was completely prevented by carefully "bleeding" the interconnected syringe system before every trial, running water through the lines to clear out all pocketed air bubbles.

Finally, fluid entering the Venturi meter was regulated using a constant-head reservoir made from a recycled PET bottle, minimizing supply pressure fluctuations and ensuring a steady flow rate during the 40-minute laboratory session.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This final chapter provides a systematic summary of the project's achievements, draws conclusions based on the empirical findings detailed in Chapter Four, and offers actionable recommendations for the future of physics education and material improvisation in Uganda. The discussion highlights how the engineered dual-module apparatus fulfills its structural design parameters and satisfies the competency-based curriculum framework.

5.2 Summary of Achievements

The primary goal of this research was to design, fabricate, and validate a low-cost, durable, and syllabus-aligned fluid mechanics instructional kit using locally available materials. This objective was successfully achieved through the assembly of two operational modules. The Fluid Statics Module successfully utilized a master-slave arrangement of graduated syringes to provide an accurate, hands-on model of Pascal's Principle and hydraulic force amplification. Concurrently, the Fluid Dynamics Module successfully combined recycled PET bottle funnels and transparent PVC conduits to create a functional Venturi flow tube with integrated piezometric manometers. This setup allowed for the immediate measurement of static pressure head drops and the direct visual mapping of laminar-to-turbulent flow transitions via a localized dye-injection network.

5.3 Conclusions

Based on the quantitative performance and experimental evaluation of the fabricated apparatus, the following conclusions are drawn:

- **Metrological Viability of Improvised Hardware:** Low-cost instructional kits built from post-consumer polymers can achieve high scientific accuracy. The Fluid Statics Module exhibited an absolute deviation of just 4.9% from theoretical hydrostatic values, while the Fluid Dynamics Module maintained an error margin of 9.2% under steady flow conditions. Both modules perform safely within the 10% maximum error threshold allowed for Advanced Level physics practicals by the Uganda National Examinations Board (UNEB).

- **Pedagogical and Economic Sustainability:** Utilizing transparent engineering-grade polymers such as PVC and PET offers a durable, highly visible, and shatter-resistant alternative to traditional imported laboratory glassware. By using locally sourced materials, this design drastically lowers fabrication costs, proving that resource-constrained secondary schools can bypass expensive import dependencies without sacrificing the quality of data collection.
- **Curriculum Alignment:** The dual-module setup fits easily within a standard 40-minute classroom lesson. It successfully transitions physics instruction from abstract chalkboard theory to active, competency-based experimentation, completely satisfying the 2025 National Curriculum Development Centre (NCDC) Advanced Level fluid mechanics guidelines.

5.4 Recommendations

To build upon the success of this project and support the broader institutionalization of practical science education in Uganda, the following recommendations are proposed:

5.4.1 For secondary school physics teachers

Physics teachers should actively embrace material improvisation using local, non-hazardous polymers to overcome the "practical deficit" in their laboratories. Instead of teaching fluid mechanics abstractly, educators can easily replicate this dual-module syringe and Venturi design using accessible community materials. This hands-on approach will help remove the intimidating, "foreign" perception of science for secondary learners and improve student performance in competency-based practical assessments.

5.4.2 For the Ministry of Education and Sports (MoES) and NCDC

The Ministry of Education and Sports, alongside the National Curriculum Development Centre, should establish formal technical training workshops for science teachers across Uganda. These professional development sessions should focus explicitly on the blueprinting, assembly, and calibration of low-cost instructional kits. Furthermore, the NCDC should integrate approved

material improvisation guides directly into the official A-Level physics teacher's guide, establishing clear standards for localized equipment fabrication.

5.4.3 For Future Researchers and Engineering Students

Future researchers should build upon this dual-module platform by integrating low-cost digital instrumentation, such as open-source microcontrollers and miniature electronic pressure transducers. This upgrade would allow for automated, real-time data logging and further reduce human error during time-synchronized discharge trials. Additionally, further research should be conducted to evaluate the long-term durability of cyanoacrylate and silicone seals under repeated classroom use across different climatic conditions in Uganda.

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APPENDIX.

APPENDIX A: MAINTENANCE MANUAL

To preserve the structural integrity, visual transparency, and metrological calibration of the dual-module fluid mechanics instructional apparatus across multiple academic cycles in a secondary school laboratory, the following maintenance protocols must be strictly observed:

1. Post-Experimental Flushing and Cleaning

Immediately following the conclusion of laboratory sessions involving the Fluid Dynamics Module, the entire horizontal PVC conduit network and the vertical manometer straws must be thoroughly flushed with clean, distilled water. This process removes any residual traces of the injected food coloring matrix. Once flushed, the control valves must be left open to allow the internal channels to air-dry completely. This prevents the accumulation of stagnant water pockets, which promotes the growth of localized algae, mold, or bacterial biofilms that can obscure the channel's transparency and alter the fluid's boundary-layer friction.

2. Environmental Storage and Ultraviolet (UV) Mitigation

The apparatus must be stored in a cool, dry equipment cabinet away from direct sunlight and high-temperature localized zones. Prolonged exposure to solar ultraviolet (UV) radiation induces photochemical degradation in the polymer bonds of the recycled bottle funnels and Polyvinyl Chloride (PVC) conduits. This UV-induced degradation causes the plastic housings to yellow, cloud over, and become highly brittle, making them prone to structural fracturing under normal handling.

3. Piston Hydraulic Upkeep and Bubble Prevention

The graduated polystyrene syringes within the Fluid Statics Module must be checked periodically to ensure the rubber seals on the plungers remain supple and airtight. If the plungers become difficult to depress, a single drop of water-soluble lubricant can be applied to the rubber gasket. Before sealing the kit away for long-term storage, the water inside the syringes and flexible

polyurethane tubing should be drained completely to prevent calcification around the nozzles, ensuring a bubble-free, incompressible fluid transmission path during subsequent deployments.

APPENDIX B: PHOTOGRAPHIC RECORD OF EXPERIMENTAL FABRICATION AND ASSEMBLY



Figure 2: IV tubes used for constructing pascals apparatus



Figure 3: set up for a venturi tube and the pascals apparatus