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Experimental Analysis of Water Jet Dynamics Using an Improvised Jet Impact Apparatus

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ABSTRACT

This study presents an experimental analysis of water jet dynamics using an improvised jet impact apparatus. The research encompassed the design, construction, and testing of the apparatus to evaluate its performance. Testing involved determining and comparing theoretical and experimental impact forces under various experimental setups. These setups included different masses (70.0 g, 100.0 g, 150.0 g) and target vanes with varied angles of impact (90°, 29.5°, 180°). The target vanes were designed with flat, conical, and hemispherical surfaces. The results indicated that the improvised apparatus achieved an overall percentage error of 17.39% in determining impact forces. Among the configurations, the hemispherical target vane combined with a 100 g mass-produced the most accurate results, with a 7.04% error. The highest percentage error of 31.6% occurred with the flat target vane and a 70 g mass. These findings suggest that while the apparatus can yield precise results under optimal conditions (e.g., hemispherical vane and 100 g mass), it may produce less accurate measurements in other configurations. Despite its limitations, the improvised jet impact apparatus demonstrates utility as a teaching and learning tool for exploring fluid dynamics, particularly the behavior of water jets. It provides an accessible means of demonstrating fundamental concepts, even if not suited for experiments requiring high precision. Overall, the apparatus serves as a valuable resource for introducing students to the principles of jet impact and fluid dynamics.

Keywords: *fluid mechanics, fluid dynamics, water jet impact, improvised apparatus, improvisation*

INTRODUCTION

Physics, as a cornerstone of scientific understanding, has consistently served as a foundation for exploring and explaining natural phenomena, from the movement of objects to the workings of the universe (Smith & Finegold, 2007). Its principles are rooted in constructing models and conducting experiments to elucidate complex concepts and foster deeper comprehension. Despite its vital role, challenges persist in effectively teaching and learning physics, especially in resource-constrained settings (Aina & Philip, 2013).

Laboratory activities play a crucial role in physics education, providing students with hands-on experiences to grasp theoretical concepts (Timmerman, 2006). These activities enhance skills such as observation, experimentation, and problem-solving, allowing learners to engage directly with the material. However, many schools, particularly in developing

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regions, face significant challenges due to a lack of laboratory facilities and equipment (Malicobon et al., 2019). This shortage hampers the ability of educators to demonstrate and students to explore key principles of physics effectively.

Improvisation offers a practical solution to these challenges. By constructing low-cost, locally sourced apparatus, educators can mitigate resource limitations while still delivering quality instruction (Tilahun et al., 2011). The use of improvised equipment not only reduces costs but also promotes creativity and adaptability among educators and students.

The improvised jet impact apparatus developed in this study offers several advantages compared to the one designed by Shariar et al. (2016). Both devices aim to analyze water jet dynamics and measure impact forces under various conditions. However, the improvised apparatus introduces a notable edge in terms of cost-effectiveness, as it is constructed from locally available and recycled materials, significantly reducing expenses. This makes it especially beneficial for educational institutions with limited resources, particularly in rural areas. In contrast, the apparatus by Shariar et al. (2016), while more sophisticated, may require specialized components that increase costs and limit accessibility.

Furthermore, the improvised apparatus is highly suited for educational purposes, as its straightforward design enables students to actively engage with experiments, promoting interactive and experiential learning in fluid dynamics. This aligns with the pedagogical goals of fostering hands-on education, as highlighted by Timmerman (2006), and addresses challenges in science education, such as the lack of laboratory equipment in underfunded schools (Malicobon et al., 2019).

The improvised apparatus is not only cost-efficient and accessible but also aligns with the educational objective of engaging students through practical experimentation. These features make it a valuable tool for institutions, especially in resource-constrained settings, while maintaining reliability comparable to more advanced systems like the one proposed by Shariar et al. (2016).

Objectives of the Study

This study focuses on analyzing water jet dynamics using an improvised jet impact apparatus, which was designed and constructed from recycled materials. This apparatus, rooted in principles of fluid dynamics, serves as a cost-effective alternative to commercial models. It enables the study of impact forces generated by a fluid jet on various surfaces, an essential concept in fluid mechanics.

Specifically, the study aimed to (1) Determine the experimental values of exit velocities and impact velocities using: (A) Masses: (a) 70.0 g, (b) 100.0 g, c. 150.0 g; and (B) Vanes: (a) Flat (θ=90°), (b) Conical (θ=29.5°), and (c) Hemispherical (θ=180°); (2) Compare the experimental and theoretical values of the impact force using the aforementioned masses and

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vanes, and (3) Calculate the percentage error between the theoretical and experimental values of the impact force across the different configurations.

By addressing these objectives, the study demonstrates the utility of improvised apparatus in enriching physics education, particularly in fluid dynamics. The findings highlight the apparatus's potential to foster understanding and engagement, even in resource-limited settings, aligning with the need for innovative solutions in science education (Greca & Moreira, 2001; Newman et al., 2018; Koponen, 2007; Yitbarek, 2021).

Theoretical Framework

One way of producing mechanical work from fluid under pressure is to accelerate the fluid to a high velocity in a jet. The jet is directed to the vanes of a turbine wheel, which is rotated by force generated on the vanes due to the momentum change or impulse that takes place as the jet strikes the vanes.

A stream of fluid from a nozzle is called a jet, which possesses kinetic energy. If this jet strikes a surface placed in its path, it will exert a force on the surface. This impressed force is known as the jet impact. From the impulse-momentum equation, the force exerted by the fluid on the surface can be found. Mechanical work can be produced from fluids by pressurizing the fluid, thereby accelerating them to very high velocities in a jet (Shahriar & Shawon, 2016).

Newton's third law of motion is applied to determine the experimental value of the force of the impact of a jet (Jameel, 2020). In the study of Hossain (2017), it was mentioned that the impulse force exerted on the target is equal to and opposite to the force which acts on the water to impart change in the direction. This concept is supported by the experiments conducted by Nanayakkara (2017), Al-Qudah (2017), and Mirdo (2017).

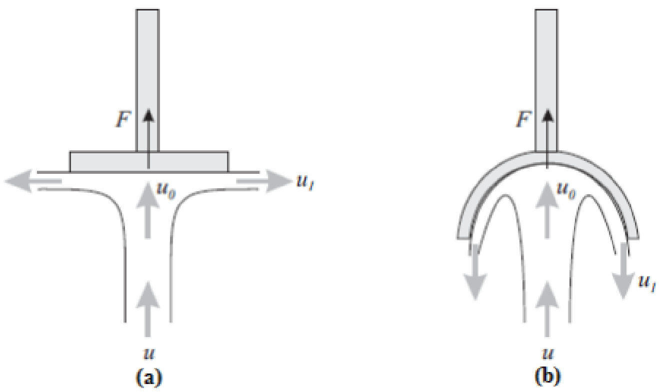

Figure 1
Force against flat and hemispherical vanes

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(Retrieved from https://www.philadelphia.edu.jo/academics/waraydah/uploads)

Moreover, in the Applied Fluid Mechanics Laboratory Manual presented by Ahmari and Kabir, the impact force is balanced by the applied weight on the weight pan, where weight is equal to the product of mass and acceleration due to gravity $W = mg$. Here mass (m) is the applied mass. Several experiment papers and laboratory manuals, such as Jameel (2020), employed this equation to determine the experimental force of impact of a jet.

Hence, to obtain the experimental value of the impact force, given different values of suspended mass targets in different shapes of the vane, the formula to be used is given as

$$F = mg \tag{1}$$

One way of producing mechanical work from fluid under pressure is to accelerate the fluid to a high velocity in a jet. The jet is directed to the vanes of a turbine wheel, which is rotated by force generated on the vanes due to the momentum change or impulse that takes place as the jet strikes the vanes (Tenaka, 2020).

Considering a jet of water that impacts a target surface, the direction of the jet is to be changed through an angle θ, as shown in Figure 1. In the absence of friction, the magnitude of the velocity across the surface is equal to the incident velocity V_i. The impulse force exerted on the target will be equal and opposite to the force which acts on the water to impart the change in direction.

Applying Newton's Second Law of Motion in the direction of the incident jet,

$$Force\ =\ mass\ \times\ acceleration$$

$$=\ mass\ flow\ rate\ \times\ Change\ in\ velocity$$

$$-F_x = m\Delta v$$

$$-F_x = (mV_{xout} - mV_{xin})$$

$$-F_X = m(V_i cos\theta - V_i)$$

$$F_X = mv_i(1 - cos\theta)$$

$$But\ m = pQ$$

$$So, F_x = pQV_i(1 - cos\ cos\ \theta)$$

$$\frac{F_x}{pQV_i} = 1 - cos\ \theta \tag{2}$$

where,

m – mass,
v – velocity,
Q – flow rate,
ρ – fluid density,
v_i – velocity,
A – area of nozzle, and
θ – angle of the target

The jet velocity can be directly calculated from the measured flow rate and nozzle exit area.

$$V_n = \frac{Q}{A} \tag{3}$$

However, as the nozzle is below the target, the impact velocity will be less than the nozzle velocity due to interchanges between potential and kinetic energy. The derivation of the equation is obtained from Morshed, Hossain, and Shetu (2018).

Applying the Bernoulli equation between nozzle and vane:

$$\frac{P_n}{\gamma} + \frac{V_n^2}{2g} + (z_n) = \frac{P_i}{\gamma} + \frac{V_i^2}{2g} + (z_i)$$

Where γ is the weight of fluid.

Since the jet is open to the atmosphere, we arrive at

$$\left(\frac{P_n}{\gamma}\right) + \left(\frac{V_n^2}{2g}\right) + (Z_n) = \left(\frac{P_i}{\gamma}\right) + \left(\frac{V_i^2}{2g}\right) + (Z_i)$$

And,

$$(Z_n) - (Z_i) = h$$

So,

$$\left(V_i^2\right) = (V_n^2) - 2gh \tag{4}$$

Where h is the height of the target above the nozzle exit.

For the *flat vane*, the target angle θ is $90°$. Since, $cos\ cos\ 90° = 0$, therefore,

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$$\frac{F_x}{\rho Q V_i} = 1 - cos\ cos\ \theta\ = 1$$

For the *conical vane*, the target angle θ is $29.5°$. Since, $cos\ cos\ 29.5°\ = 0.870$, therefore,

$$\frac{F_x}{\rho Q V_i} = 1 - cos\ \theta = 0.129$$

For the *hemispherical vane*, the target angle is $180°$. Since, $cos\ cos\ 190°\ = -1$, therefore,

$$\frac{F_x}{\rho Q V_i} = 1 - cos\ \theta = 2$$

From the abovementioned equations, it is possible to compare the experimental and theoretical force values for the target vanes with different impact angles.

Theoretically,

$$F = \rho Q V_i (1 - cos\theta) \quad (5)$$

Experimentally,

$$F = mg$$

Further, nozzles with different diameters have a great impact on jets. Cho et al. (2019) stressed that the jet nozzle is one of the most important components of a water jet system. It is directly related to the shape and divergence properties of the water jet. Therefore, changes in the nozzle diameter will bring about new types of water jets.

Marinescu et al. (2012) discussed that a simple jet nozzle is a round orifice with a small length-to-diameter ratio, ideally less than 0.25. A jet of fluid emerges from the orifice at high speed. With sufficient flow and momentum, a round jet is a suitable way to achieve a high-speed jet that can be sustained for more than 25 cm. The high-speed jet operates similarly to a fire hose or garden hose nozzle.

Moreover, when a high-pressure water jet impacts a solid surface, the velocity vectors of the high-speed fluid change, which may lead to a momentum loss of the water jet. As is known, this lost momentum will transfer to the impact force *F* acting on the solid surface. According to the momentum theorem, the impact force can be calculated as follows:

$$F = \rho Q v (1 - cos\theta), \quad (6)$$

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Where ρ is the density of the fluid, Q is the flow rate, v is the jet velocity, θ and is the angle between the wall surface and the reflecting direction of the fluid after impacting the object. The impact force F calculated by the formula is the total impact force of the jet acting on the solid surface.

METHODOLOGY

The following section outlines the research design, the construction and testing process, and the data-gathering procedures employed in the study.

Research Design

This study used the experimental method of research and was divided into three phases as follows:

Phase I. This phase covered the design and construction of the improvised apparatus.

Phase II. This phase covered the testing and gathering of data through experimentation.

Phase III. This phase covered the analysis and interpretation of the data gathered in the study. This phase also includes determining the percentage of error between the experimental and theoretical data gathered from the study.

Construction and Testing

Jet Impact Apparatus. The following materials were used for the construction and testing of the improvised jet impact apparatus: nozzle (diameter of 0.001210 m), PVC pipes (for the water to flow), control valves, and a pressure gauge (to control the flow of exiting water and determine the pressure given by a stored pressure from the pressure tank), a spring (to hold the rod and mass in place), and three target vanes of different angles (90°, 29.5°, 180°).

The improvised jet impact apparatus consisted of a 0.5 horsepower water pump to push the water vertically, a transparent cylindrical frame that serves as a housing for the water jet and different target angles, a lid for the top opening of the cylinder, a metal rod with lock screws, and a timer device to measure how fast is the exiting flow of water from the jet impact apparatus, and a volumetric tank.

The apparatus is made up of a cylindrical glass frame that serves as the housing of different target vanes and the connecting PVC pipe and the nozzle. The base is a plastic lid with two holes for entering and exiting water through PVC pipings. Above the cylindrical glass frame is a metal lid with a hole for the different target vanes. Also, a metal rod is connected

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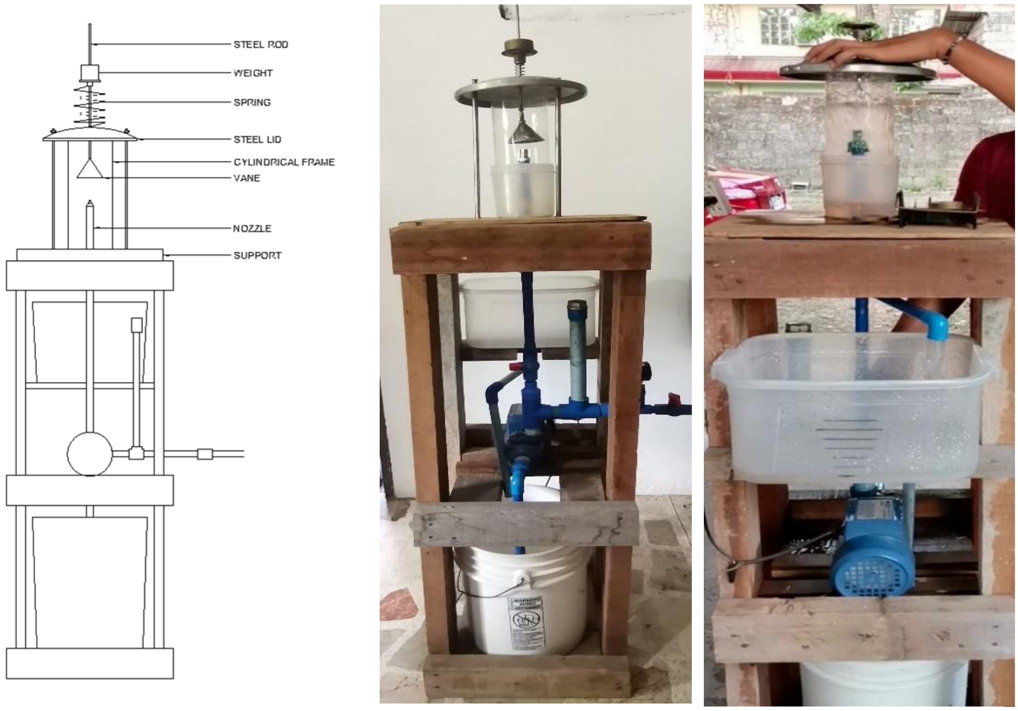
to the vane on the upper part of the lid. On the metal rod, there is a plate for the placement of the slotted mass, and underneath is a spring.

Bench. The bench comprises four pieces of 4 x 2 pieces of wood that measure 1.27 meters long each and a 4 x 2 piece of wood of length 0.4 meters for each supporting frame. A 0.4 x 0.30-meter piece of plywood for both ends of the bench for the placement of the jet impact apparatus and pail that serves as the reservoir. Along with it are a 240V water pump, connecting pipe, water valve, pressure gauge, pressure tank, and a container that serves as the volumetric tank.



(a) (b) (c)

Figure 2

(a) Schematic Diagram of the Jet Impact Apparatus, (b) the constructed improvised jet impact apparatus, and (c) the experimental setup.

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Data Gathering Procedure

The following procedure was followed in gathering the needed data to test the improvised apparatus.

1. The impact apparatus was set up as shown in Figure 2c.
2. The diameter of the nozzle was determined, and the distance between the nozzle and the target (*h)* was measured.
3. The weight was brought to the zero position.
4. The flow control valve was opened. (The water from the jet will strike the vane and be deflected. The vane along with the weight, will be raised to a certain height.)
5. The level of the vane and weight cup was brought to the original position using the weights.
6. Water in the measuring bucket will be collected, and the collection time will be noted.
7. The weight on the weight cup is changed, and the balance of the weight cup is maintained by regulating the flow rate. (Each time, the weight pan is checked to see if it is balanced.)
8. The control valve is closed, and the pump is switched off.
9. The experiment is repeated with different target vanes.
10. The area was calculated, the volume of water was determined, and the flow rate was computed.
11. The nozzle exit velocity was calculated from the flow rate.
12. The impact velocity and value of h were calculated.
13. The experimental and theoretical impact forces were determined and compared.
14. The percentage error between the experimental and theoretical values of the impact forces was calculated.

RESULTS AND DISCUSSIONS

Experimental Values of Exit Velocities and Impact Velocities

The theoretical values of the impact force of the flat, conical, and hemispherical vanes were 0.8672 N, 0.8824 N, and 0.8267 N, respectively. The experimental values of the impact force corresponding to the masses of 70 g, 100 g, and 150 g were 0.6867 N, 0.9810 N, and 1.4715 N, respectively, for all target vanes. The 150 g mass yielded the highest theoretical values of the impact force of 1.2605 N, 1.1924 N, and 1.3104 N for the flat, conical, and hemispherical target vanes, respectively. The higher values of the added mass correspond to higher experimental and theoretical values of the impact force, and lower values of added

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mass correspond to lower values of the impact force.

Table 1
Experimental Values of the Exit Velocity and Impact Velocity

Mass (g)	V_n (m/s)	V_i (m/s)
Flat Vane (θ = 90º)		
70.00	2.2241	2.0401
100.00	2.7433	2.5964
150.00	3.3707	3.2522
Conical Vane (θ = 29.5º)		
70.00	6.2564	6.1934
100.00	7.6959	7.6448
150.00	8.9654	8.9215
Hemispherical Vane (θ = 180º)		
70.00	1.9810	1.7718
100.00	2.2356	2.0526
150.00	2.4706	2.3063

Comparison of the Experimental and Theoretical Values of the Impact Force

Table 2
Percentage Error between the Theoretical and Experimental Values of the Impact Force

Vanes	Mass (g)	Experimental Value, F_{exp} (N)	Theoretical Value, F_{theo} (N)	Percentage Error (%)
Flat	70.0	0.6867	0.5218	31.61
	100.0	0.9810	0.8190	19.77
	150.0	1.4715	1.2605	16.74
Conical	70.0	0.6867	0.5777	18.88
	100.0	0.9810	0.8771	11.85
	150.0	1.4715	1.1924	23.41
Hemispherical	70.0	0.6867	0.8072	14.93
	100.0	0.9810	1.0553	7.04
	150.0	1.4715	1.3104	12.30
		Mean Percentage Error		**17.39**

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The improvised jet impact apparatus produced an overall percentage error of 17.39% in the determination of the impact force. The hemispherical target vane and the 100 g mass yielded the lowest percentage error (7.04%). The highest percentage error (31.6%) was recorded for the 70 g mass and flat target vane experimental setup.

The 7.04% error observed under the optimum condition, with a hemispherical vane and a 100 g mass, can be attributed to a combination of primary and secondary factors. The primary cause of this error likely stems from measurement inaccuracies due to the limitations of the improvised apparatus. Tools such as the pressure gauge, flow meter, and timing mechanisms may lack the precision of commercial-grade equipment, leading to slight deviations in recorded water jet velocities, flow rates, and impact forces. Additionally, imperfections in the recycled and locally sourced materials used for the apparatus, such as irregularities in the nozzle or the surface of the hemispherical vane, could influence the consistency of the water flow and force distribution.

Environmental factors, including temperature and humidity, may also contribute to the error by subtly altering the water's viscosity and density, which are critical to accurate force measurements. Furthermore, friction and oscillations in the mass-support mechanisms might slightly affect the force transmitted to the measuring components. Misalignments in the experimental setup, such as improper orientation of the vane or placement of the mass, could also introduce deviations from expected results, as even small angular shifts can affect force distribution and deflection. Lastly, human error during manual operations, such as resetting weights, operating valves, and recording data, can further contribute to inconsistencies.

Despite these challenges, the relatively low percentage of error under optimal conditions demonstrates the reliability of the improvised apparatus. Addressing these factors through improved materials, enhanced calibration, and refined experimental procedures could further enhance the apparatus's accuracy, reinforcing its utility as a cost-effective educational tool for fluid dynamics studies.

CONCLUSIONS

Based on the findings of the study, several conclusions were drawn. The various experimental setups of the improvised jet impact apparatus, which included added mass and target vanes, produced differing exit and impact velocities, with an increase in added mass leading to higher exit and impact velocities. Additionally, the setups generated varying impact force values, revealing a direct relationship between impact force and added mass. The improvised apparatus demonstrated accuracy in determining the impact force of a water jet on a target surface when using the hemispherical vane and a 100 g mass. However, in other setups with different target vanes and added masses, the apparatus may not produce precise results for determining impact force. Therefore, it is more suitable for experiments that do not demand high accuracy. Overall, the improvised apparatus can effectively support teaching and learning fluid dynamics concepts, particularly the dynamics of water jets.

RECOMMENDATIONS

Based on the findings of the study and the conclusions drawn, it is recommended that the improvised jet impact apparatus be utilized for laboratory demonstrations and experimentation of fluid dynamics concepts, particularly the dynamics of water jets. Further experimental studies are encouraged, using target vanes other than the flat, conical, and hemispherical ones to assess the effectiveness of the improvised apparatus in determining impact forces. Additionally, modifications to the design and construction of the apparatus, such as incorporating a pressure switch for more accurate pressure gauge readings and improved control of water flow from the reservoir, are suggested. Future experiments should also consider other factors, such as spring oscillations and friction on the upright rod, to enhance the accuracy of the improvised apparatus and yield better results.

ETHICAL STATEMENT

This study strictly followed the principles of research integrity, upholding accuracy, transparency, and honesty throughout data collection and analysis. As no human or animal subjects were involved, all experimental procedures were carried out in accordance with applicable safety and environmental standards.

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REFERENCES

Aina, J. K., & Philip, O. F. (2013). Improving students' interest in physics through the use of improvised instructional materials in senior secondary schools in Ekiti state, Nigeria. *International Journal of Research Studies in Educational Technology, 2*(1), 77–87. https://doi.org/10.5861/ijrset.2013.234

Greca, I. M., & Moreira, M. A. (2001). Mental, physical, and mathematical models in the teaching and learning of physics. *Science Education, 86*(1), 106–121. https://doi.org/10.1002/sce.10013

Koponen, I. T. (2007). Models and modeling in physics education: A critical re-analysis of philosophical underpinnings and suggestions for revisions. *Science & Education, 16*(7–8), 751–773. https://doi.org/10.1007/s11191-006-9000-7

Malicobon, R. A., et al. (2019). Challenges in science education in the Philippines: The role of laboratory equipment.

Newman, D. L., Stefkovich, M., Clasen, C., Franzen, M. A., & Wright, L. K. (2018). Physical models can provide superior learning opportunities beyond the benefits of active engagements. *Biochemistry and Molecular Biology Education, 46*(5), 435–444. https://doi.org/10.1002/bmb.21159

Shariar, S. M., Rahman, S., & Alim, M. A. (2016). Experimental and numerical study of water jet impact force using a lab-scale apparatus. *Journal of Fluid Mechanics Education.*

Smith, J. J. A., & Finegold, M. (1995). Models in physics: Perceptions held by final-year prospective physical science teachers studying at South African universities. *International Journal of Science Education, 17*(5), 621–634. https://doi.org/10.1080/0950069950170506

Tilahun, T., et al. (2011). Strategies for overcoming resource constraints in African science education: The case of physics teaching.

Timmerman, M. C. (2006). Laboratory activities in science education: Engaging students in hands-on learning.

Yitbarek, S. (2021). Roles of laboratory activities in science education: A pedagogical perspective.