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# Revolutionizing Ripple Tank Experiments: Innovative Tools to Enhance the Wave Phenomena and Characteristics Learning

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**Abstract**

The ripple tank is one of the important experimental tools for teachers and students in the teaching and learning of wave physics. It is necessary for teachers to demonstrate various phenomena related to water waves for better students' understanding. However, it is often less ideal to carry out the experiment using a conventional setup outside the laboratory setting due to its lack of portability. This study develops a portable ripple tank to enhance the teaching experience in wave phenomena and characteristics. Traditional ripple tanks face limitations in terms of size, portability, and observation clarity, prompting the need for innovation. The proposed portable ripple tank addresses these challenges by integrating low-cost materials and electronic components to improve accessibility and functionality. This study aimed to design and evaluate a portable ripple tank integrated with digital components to enhance classroom usability and learning outcomes. Through the adoption of the ADDIE instructional design model, the study systematically analyzes the needs of 20 physics teachers through semi-structured interviews and direct observations, which enables the key issues with existing ripple tanks in school laboratories to be identified. Subsequently, the portable ripple tank was designed and developed, incorporating features such as a digital stroboscope and an alternative power supply for enhanced usability. In the implementation, five-wave experiments were conducted using the tool to evaluate its effectiveness in teaching key wave concepts such as reflection, refraction, diffraction, and interference. In evaluation phases, the effectiveness of the portable ripple tank is assessed by three expert teachers, who assess the tool's usability and effectiveness in classroom settings, confirming its practicality, affordability, and impact on students' understanding. This research contributes to the advancement of wave physics education by providing educators with a versatile and user-friendly experimental tool, enabling students to visualize and understand complex wave concepts with ease.

**Keywords:** ADDIE, portable, ripple tank, stroboscope, wave phenomena.

## INTRODUCTION

Wave is one of the fundamental physics topics that commonly requires laboratory activities for practical exploration and understanding of its properties and behaviors. According to the constructivist learning theory, learning occurs when students actively construct knowledge based on their experiences rather than passively receiving information (Allen, 2022; Efgivia et al., 2021). Hands-on experiments can build meaningful connections between theoretical concepts and real-world applications, such as investigating wave reflection, refraction, diffraction, and interference.

Observing natural waves helps students understand wave physics. These waves include both transverse and longitudinal movements. Surface-water waves are especially effective for practical exploration because they are easy to see and study. Over time, the teaching of wave physics has evolved, incorporating effective utilization of devices demonstrating water waves (Thepnurat et al., 2020). Various tools have been employed to observe and study wave phenomena, including ripple tanks, wave meters, and stroboscopes. These tools provide visual and quantitative insights into wave properties, allowing students to experiment and analyze wave behaviours in controlled settings. Ripple tanks are commonly used in demonstrating wave phenomena such as wave propagation, reflection, diffraction, and interference, which can be visualized as projected bright and dark patterns on a screen (Yapo, Seesombon, Chattrapiban & Pussadee, 2018). There are two main types of waves, mechanical waves and electromagnetic waves. As waves, both types share common characteristics, including wavelength, period, propagation, reflection, refraction, diffraction, interference, and more (Thy & Iwayama, 2021). A mechanical wave is a disturbance that travels through several media, with water being one of the media. A ripple tank is a tool used to investigate the motion of waves on the surface of the water and to observe the pattern of water waves (Janah, Sugita, Hartono, & Supriyadi, 2019). Ripple tanks have long been essential for exploring wave properties, including reflection, refraction, diffraction, and interference. However, the conventional ripple tank used in schools presents several challenges that need addressing. Its large size and lack of portability confine its use mainly to the laboratory, limiting where experiments can be conducted. Another issue lies in the quality of visuals the existing setup provides, especially when paired with handheld stroboscopes. These devices, with their tendency for loose bearings and holder issues, can make it difficult for students to observe the water wave at a consistent frequency. This inconsistency often leads to inaccurate measurements and hampers the overall learning experience. As a result, students may struggle to grasp key concepts related to wave behavior and properties entirely.

Previous studies have explored digital tools such as smartphone-based measurement apps and LED lighting to overcome some of these issues (Westhoff & Pusch, 2023; Thepnurat et al., 2020). For instance, Thepnurat et al. (2020) demonstrated how smartphone applications can measure wave properties in a DIY ripple tank setup, improving student accessibility. Westhoff and Pusch (2023) presented a low-cost ripple tank experiment incorporating 3D printed components and an Arduino-based control unit, enhancing the digital integration of traditional experiments. These innovations have contributed to cost reduction and improved functionality. However, few tools combine portability, clarity, affordability, and usability. This research aims to develop a wave analyzer that is easy to carry, shows clear wave patterns, is low-cost, and simple to use, making it suitable for any classroom or science activity.

This study responds to that gap by designing, constructing, and evaluating a low-cost, portable ripple tank. Through teacher-driven needs analysis and iterative development, this research aims to develop a novel portable ripple tank as an innovative experimental tool to enhance the teaching experience in wave phenomena and characteristics. The benefit of this research is that it enables a deeper understanding of wave properties, including reflection, refraction, diffraction, and interference, through hands-on experimentation. Thus, physics educators and students can use this experimental tool to improve their comprehension of wave mechanics in physics education.

## METHOD

This study employed a qualitative research design in which the ADDIE instructional design model was adopted as the foundational framework for developing and evaluating a portable ripple tank. The research process was structured into two key components: project development and evaluation, both were systematically guided by the five stages of the ADDIE model: analysis, design, development, implementation, and evaluation. The phase of the ADDIE development model is briefly presented in Figure 1.

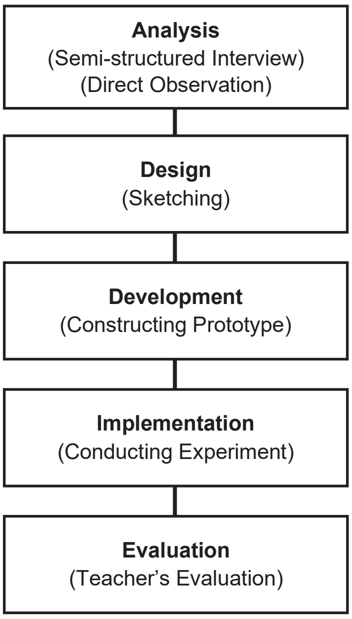


**Figure 1.** ADDIE development phase and process.

The ADDIE model is a key instructional design framework that guides effective and efficient project development (Stapa & Mohammad, 2019; Aldoobie, 2015). It adapts to different contexts and supports systematic planning, continuous feedback, and ongoing improvements (Syaharani, Muharam, Prima & Winarno, 2024). Each phase helps ensure that learning tools effectively meet learner needs and address instructional challenges clearly and efficiently.

In the analysis phase, data collection techniques included semi-structured interviews and direct observations in laboratory and classroom settings. The interviews were designed to investigate the limitations of conventional ripple tanks and gather insights into user needs, teaching challenges, and desired features for improved wave learning tools. A total of 20 physics teachers were selected using purposive sampling, ensuring participants had active teaching roles and relevant experience with wave physics. One of their schools was chosen to observe the existing laboratory ripple tank directly. Thematic analysis was used to interpret interview transcripts, with observational data coded and categorized to extract meaningful insights.

In this phase, employing a teacher interview method involves engaging educators in structured discussions to gain insights into their perspectives, experiences, and practices within the classroom setting. These interviews offer a valuable opportunity to delve into teaching strategies, challenges faced, and innovative approaches used by educators. The following are examples of questions designed for a semi-structured interview, explicitly focusing on the use of ripple tanks in teaching wave phenomena. These questions aim to explore educators' experiences, challenges, and perspectives on integrating ripple tanks into their lessons and potential innovations to enhance their effectiveness.

**Question 1**: “What are the challenges faced regarding the size and portability of traditional ripple tanks, and how does this affect the teaching practices?”

**Question 2:** “How does the difficulty in using hand stroboscopes influence students’ ability to observe and understand wave patterns effectively?”

**Question 3:** “How do cost and maintenance issues impact the accessibility and usage of conventional ripple tanks in physics education?”

Additionally, direct observation involves systematically observing laboratory activities, providing rich qualitative data for analysis. The lab observation method was implemented based on several aspects: the type of ripple tank used in the school, the method of operating the ripple tank, the laboratory environment at the school, and the needs of the equipment in the laboratory. By combining these two methods, researchers can triangulate data, enhancing the validity and reliability of findings while gaining a comprehensive understanding of teaching practices and their impact on student learning outcomes. This approach offers more profound insight into effective teaching strategies.

Based on this data, the project was designed and developed to solve the problem and improve the existing ripple tank. In the implementation and evaluation phase, three expert teachers with over 15 years of experience were invited to test the effectiveness of the portable ripple tank and validate the project and qualitative data from teacher evaluations were thoroughly synthesized, offering a comprehensive assessment of the prototype's educational value and its potential impact on the learning process.

## RESULT AND DISCUSSION

### Phase 1: The Analysis

In the analysis phase, the instructional issue is defined, the goals and objectives of the instruction are set, and the learning environment, along with the learners' current knowledge and skills, are assessed (Adeoye, Wirawan, Pradnyani & Septiarini, 2024).

**a. Interview Session**

A total of 20 physics teachers (P1-P20) from the public sector school participated in the semi-structured interview, which is commonly used in qualitative research due to its flexibility and adaptability (Kallio, Pietilä, Johnson & Kangasniemi, 2016). One of its key advantages is fostering reciprocity between the interviewer and participant (Mashuri, Sarib, Rasak & Alhabsyi, 2022). The interview data were carefully analyzed and coded systematically to ensure reliability and consistency in the findings, providing a clear understanding of the insights (Xue, Ahmad & Liu, 2023). Table 2 shows a sample of the interview coding and transcribed data for the teacher's interview.

**Table 2.** The coding and transcription data for the teacher's interview.

| Quotes | Codes | Categories |
|---|---|---|
| ...cost and maintenance issues make it challenging to incorporate them into our lessons effectively... P1, P5, P7, P8 | Cost and maintenance | Cost of the existing ripple tank |
| ...the high cost of the setups makes it challenging to justify purchasing them, especially when we have limited funds... P2, P3, P9 | High cost | |
| …size and portability of the ripple tank. It's often cumbersome to set up… P1, P4, P11, P12 | Size and portability | Portability of the existing ripple tank |
| …impossible to move without a team of people to help… P13, P14, P15 | Need team | |
| …the ripple tank's unwieldy nature limits its use in various learning spaces… P7, P18, P19 | Different learning spaces | |
| …struggle to observe wave patterns on the stroboscope's rotating disc, especially in well-lit environments… P6, 16, 18 | Struggle | Hand stroboscope |
| … hand stroboscopes are finicky, needing frequent calibration to sync with wave frequency… P10, P17, P20 | Finicky | |
| ...can be frustrating since you must adjust them to see the waves… P5, P13 | Frustrating | |

Based on the interview results, three main challenges hinder the effective use of ripple tanks and associated tools in teaching wave phenomena: cost, portability, and hand-held stroboscopes. Firstly, many teachers reported that the high cost of existing ripple tank setups makes it difficult for schools to invest in them, especially when budgets are limited. Participants expressed concern over the initial purchase price and ongoing maintenance costs, which often cannot be justified when other priorities compete for funding. This issue restricts the availability of ripple tanks in classrooms, limiting students' exposure to hands-on demonstrations.

Secondly, the ripple tank's size and lack of portability emerged as a significant concern. Teachers explained that the equipment is often large, heavy, and cumbersome to set up, making it impractical to move between classrooms or adapt to different learning spaces. Some even stated that a team of people is needed to reposition the tank, which further discourages frequent use. Its bulky design limits its practicality, especially in schools with smaller classrooms or limited space.

Thirdly, the use of the hand stroboscope presents technical difficulties. Several participants shared that it is hard to observe clear wave patterns using the stroboscope, particularly in well-lit environments where visibility is compromised. The tool was described as finicky, requiring frequent calibration to match the wave frequency, which can be time-consuming and disruptive during lessons. Some teachers found it frustrating to adjust, as even small misalignments can obscure the wave visuals entirely, reducing the effectiveness of the demonstration.

In summary, the' high cost, limited portability, and complexity of handheld stroboscopes present significant barriers to integrating wave demonstrations into classroom teaching. Addressing these issues by developing more affordable, portable, and user-friendly alternatives could enhance the effectiveness of physics education, allowing students to engage more meaningfully with wave concepts.

**b. Direct Observation**

The direct observation method was implemented by choosing one of the public sector schools. Observation of the existing ripple tank is carried out in the laboratory. Examining the laboratory's efficiency is the aim of achieving various goals (Hofstein, 2017). The observations are based on several aspects: the type of ripple tank used in the school, the method of operating the ripple tank, and the equipment needs in the laboratory. Table 3 shows the results of the direct observation method on the existing ripple tank in the school laboratory.

Based on the observation, the school uses a basic model of ripple tanks, particularly those with a bottom-view design. However, these ripple tanks may offer limited visibility and less detailed observation of wave patterns, making it challenging to conduct more complex experiments or comprehensively understand wave behavior. The ripple tanks are powered by a larger direct current (DC) power supply. In a physics laboratory, a DC power source is frequently utilized for experiments that require a constant voltage or current. However, the equipment can be cumbersome due to its bulky size and weight. Next, the finding shows that some of the laboratory's equipment needs to be maintained or repaired. This suggests that some equipment may be faulty or inadequate, potentially compromising the reliability of ripple tank research results.

**Table 3.** The findings of direct observation.

| Aspect | Observation | Findings |
|---|---|---|
| Types of Ripple Tank Used | Basic Model | Bottom view of the ripple tank |
| Method of Operation | Direct Current Power Supply | Bigger size power supply |
| Equipment Needs | Maintenance required | Some equipment needs to be repaired |

**Phase 2: Design**

The 3D design is suitable for project sketching in the development process. In this case, online tools are applied using technology-provided facilities. Programs such as Tinkercad, 3Dtin, ShapeSmith, Cubify, and Autodesk 123D design are examples of the online tools used (Eryilmaz & Deniz, 2021). These programs allow users to create simple or complex object design modelling (Karaismailoglu & Yildirim, 2023).

In this research, the sketching process was done using Tinkercad. Tinkercad utilizes WebGL technology, enabling the rendering of 3D graphics directly within a web browser. This eliminates the need for installing extra software; all that's required is a browser supporting WebGL, such as Chrome, Firefox, or Opera 12 Alpha (Kadeeva, Klyuchnikov, Kuprieva & Drozdva, 2020).

Using premade projects or creations, the 3D sketch design was developed using Tinkercad since this online tool is simple and does not require installation (Avila & Bailey, 2016). Its ease of use, flexibility, and intuitive interface make it ideal for quick and effective design creation. With various tools and features, Tinkercad enables precise modeling and visualization while improving precision innovation productivity. Therefore, Tinkercad was selected as the primary tool for creating the 3D model due to its accessibility and effectiveness in supporting the early design development stages.

In this study, the project sketch was carefully developed and refined using Tinkercad, resulting in a detailed 3D model visually representing the initial concept, as illustrated in Figure 2. This model is a foundational representation for further development and prototyping in the design process. Additionally, it allows for easy modification as the project progresses, ensuring flexibility in the design. Iteration.

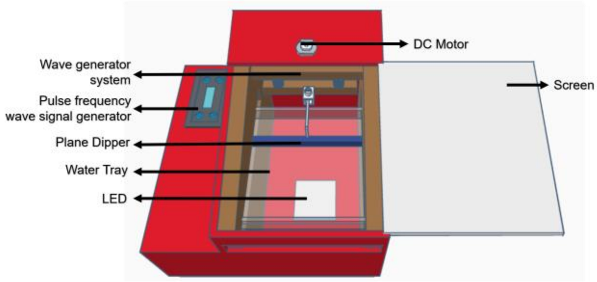


**Figure 2.** A sketch of the portable ripple tank created using Tinkercad.

**Phase 3: Development**

Development is the primary process to construct the portable ripple tank. This phase involves creating and building all content and components based on the design phase (Spatioti, Kazanidis, & Pange, 2022). This process is divided into two parts, which are the body and the electronic part. Both parts were built using readily available, reusable materials, and not too expensive for electronic components. By prioritizing accessibility and affordability, the portable ripple tank is a valuable resource for all.

**a. Body Part**

The materials for the portable ripple tank were chosen for durability, functionality, and ease of assembly. The body of the tank consists of five main components: the frame, base, tray, screen, and wave dipper, each serving a specific purpose in enhancing the teaching and learning experience in wave phenomena. The frame is made of reusable wood, chosen for its strength, tensile strength, and resistance to compression, providing sturdy support. The body cover is made of polyplast board, known for its waterproof, impact-resistant, and lightweight properties, which protect the components and make the tank easy to handle and transport. Transparent acrylic sheeting is used for the screen and water tray, providing clarity, brilliance, and optical transparency. With glass-like properties, half the weight, and superior impact resistance, it ensures clear visuals of wave patterns, enhancing the learning experience. Lastly, the wave dipper is constructed using paper clips, chosen for their flexibility, strength, and low cost. Typically made of steel, paper clips provide the rigidity to create precise wave motions while being reusable and readily available. The complete prototype is shown in Figure 3.

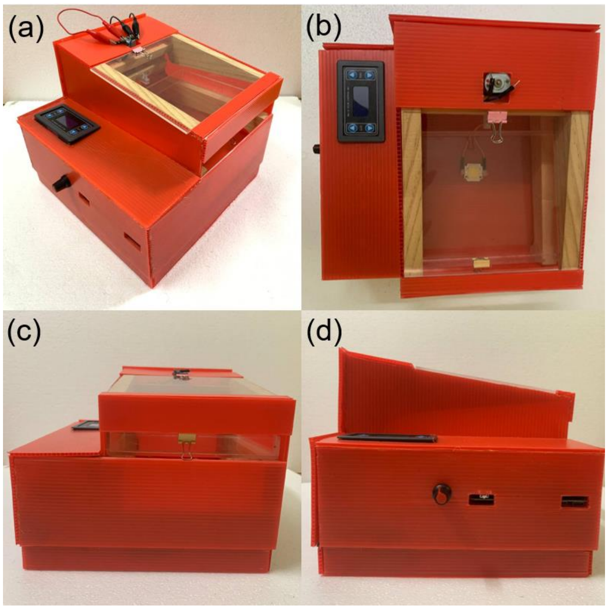


**Figure 3.** The portable ripple tank views from (a) perspective view, (b) top view, (c) front view, and (d) side view.

**b. Electronic Part**

The electronic components of the portable ripple tank are carefully chosen to enhance functionality and performance, focusing on the wave generator, digital stroboscope, and power system. The wave generator, which plays a vital role in producing water waves, operates using a direct current (DC) motor. This motor is controlled by a pulse width modulation (PWM) motor speed controller module, allowing for precise adjustments in the motor's speed and ensuring the consistent generation of waves. Integrating the DC motor and PWM controller enables efficient wave production by offering smooth and reliable control over wave frequency and amplitude. This is essential for accurate experiments and demonstrations in the ripple tank setup. These components work in tandem to generate waves of varying frequencies by adjusting the speed of the DC motor through the PWM motor speed controller. The DC motor in the wave generator section is shown in Figure 4.

**Figure 4.** Wave generator system for producing water waves.

The wave generator section was constructed from wood and attached to two springs. The load assembled with the DC motor amplified vibrations, causing the wave generator to oscillate. The springs ensure elastic movement for consistent water waves. Additionally, the wave dipper can be quickly replaced using a lock for easy adjustments in different wave experiments. The two types of dippers are shown in Figure 5.

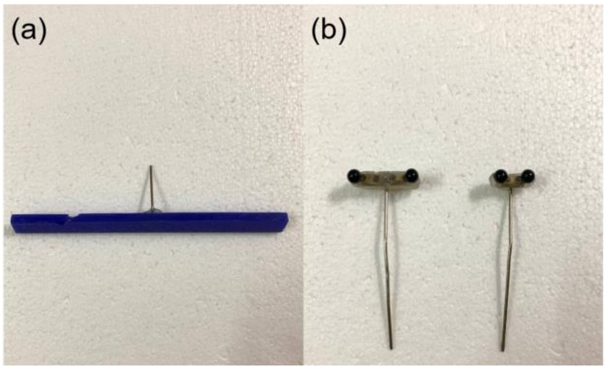


**Figure 5.** The wave dipper for generating a water waveform (a) plane wave, and (b) circular wave dipper.

The two dipper types produce different waveforms: the plane wave dipper for reflection, refraction, and diffraction, and the circular wave dipper for interference phenomena. The digital stroboscope is a key component of the portable ripple tank, measuring the cyclic speed of an object

(Dhali, Rahman, Islam & Nasim, 2015). It uses an LED connected to a pulse frequency generator, producing a blinking light synchronized with the frequency to create a static water waveform, as shown in Figure 6.

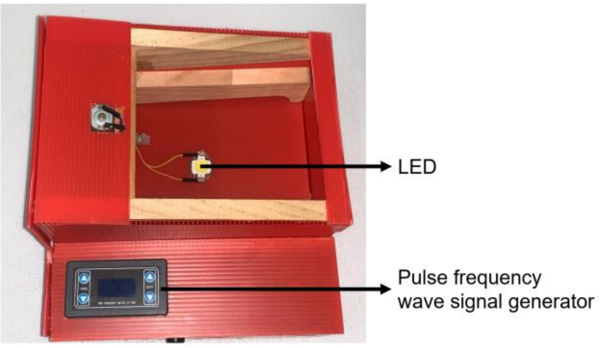


**Figure 6.** The digital stroboscope system is used to freeze the motion of the image of water waves.

Refer to Figure 6, where the LED is positioned at the bottom of the water tray. This placement allows the LED light to project the wave image from below onto the screen at the top of the portable ripple tank, making the wave patterns visible for observation and analysis. As the waves propagate through the water, their height and motion variations cause fluctuations in the light intensity projected onto the screen, effectively capturing the wave behavior in real time. The pulse frequency generator module has been installed within the body of the portable ripple tank to control the flashing frequency of the stroboscope. The input frequency changer on the stroboscope functions by adjusting the pulse output frequency, which directly influences the flash rate of the stroboscopic light. This frequency control allows users to manipulate the visualization of the wave motion. When the strobe frequency matches the wave frequency, the waves appear stationary due to the stroboscopic effect.

The portable ripple tank's effectiveness is due to two systems, i.e., a wave generator and a digital stroboscope. However, both systems required electrical power to operate the wave generator and digital stroboscope fully. Lithium-ion batteries are rechargeable batteries that have become integral to modern electronic devices due to their high energy density, long cycle life, and lightweight characteristics (Li, Lu, Chen & Amine, 2018; Manthiram, 2017). The two-channel 18650 lithium battery shield v8 mobile power expansion board has been used as an energy source to supply electricity from the lithium-ion battery to all components. The battery shield provides two types of charging input, using micro- or Type-C USB. This battery shield supplied 5 V to the wave generator and digital stroboscope system from the lithium-ion battery.

**Phase 4: Implementation**

Five experiments were conducted: a determination of wavelength, frequency, wave speed, reflection, refraction, diffraction, and interference of water waves. These experiments were conducted using the portable ripple tank that offered students hands-on experience and a deeper understanding of wave phenomena. Hands-on experience can shape individuals' perceptions and attitudes towards specific practices or methods by providing them with firsthand knowledge and allowing them to form informed opinions based on personal experiences (Kanapathy & Azhari, 2024; Ekwueme, Ekon & Ezenwa-Nebife, 2015). The portable ripple tank enabled students to visualize and analyze wave patterns in real time, making learning about waves interactive and engaging.

**a. Determination of Wavelength, Frequency, and Wave Speed**

Wavelength, wave speed, and frequency are key concepts in wave study and are essential for understanding natural phenomena and technology. Frequency refers to the number of wave oscillations passing a fixed point per second and is measured by counting these oscillations. Wave speed, v, is the distance a wave travels in a given time, t. The equation can represent wave speed or velocity:

$$v = \frac{d}{t} \quad (1)$$

Wave speed is also related to both wavelength and wave frequency. Wavelength is the distance between two corresponding points on adjacent waves. Wave frequency is the number of waves passing a fixed point in a given time. This equation shows how the three factors are related:

$$v = \frac{f}{\lambda} \tag{2}$$

The fundamental properties of waves, including wavelength, frequency, and wave speed, are generally introduced early in exploring wave phenomena (Kotsis, 2024). The properties of this portable ripple tank have been determined. The plane dipper was used to form a plane wave with frequencies 15 Hz, 22 Hz, 27 Hz, and 31 Hz—the experiment setup is shown in Figure 7.

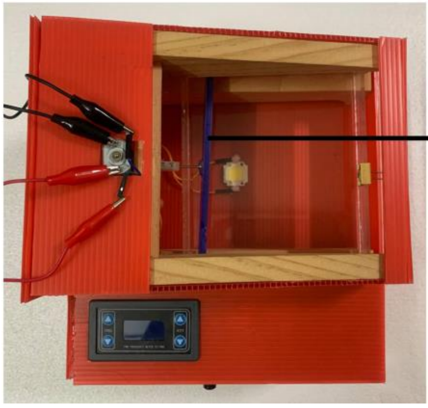


**Figure 7.** The plane dipper is used to generate plane waves in the ripple tank.

The image of the wave on the screen appeared static due to the effect of the digital stroboscope, which operated at a frequency equal to that of the wave source. This precise synchronization between the stroboscope and the wave source caused the wave to appear motionless, as the stroboscopic flashes occurred precisely when the wave was in the same position during each cycle, effectively freezing the wave's motion. As a result, the wave seemed to remain stationary, providing a clear and consistent visual representation of the wave pattern. The blue double-arrow line in the image illustrates the wavelength patterns for different frequencies, clearly highlighting the changes in the wavelength as the frequency varies, as shown in Figure 8. This technique allowed for a detailed examination of the wave characteristics without the interference of motion blur.

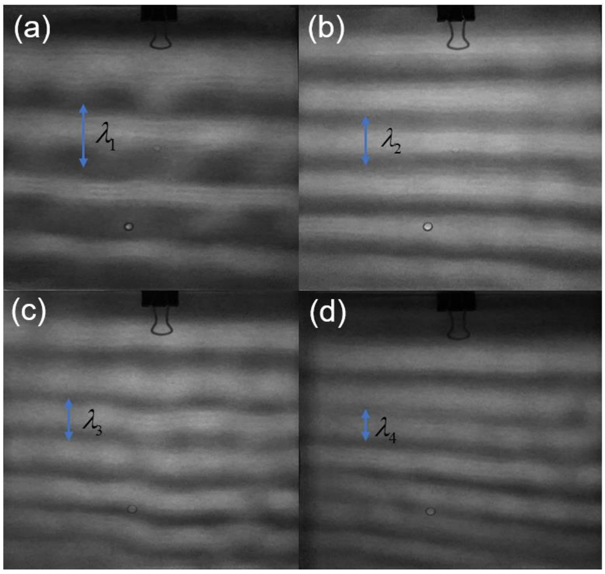


**Figure 8.** Wave plane pattern for (a) 15 Hz, (b) 22 Hz, (c) 27 Hz, and (d) 31 Hz.

The variation frequency of the water wave formed different wavelengths. The image of standing waves clearly showed the relationship between wave speed, frequency, and wavelength according to equation (2). From the equation, the wavelength value is inversely proportional to the wave frequency. All the values of wave speed have also been determined using equation (2). The wavelength, wave frequency, and inverse of frequency values have been recorded in Table 4.

In Table 4, the wavelength value is directly proportional to the inverse of the frequency, indicating a clear mathematical relationship between these two wave properties. This inverse proportionality suggests that as the frequency of the wave increases, the corresponding wavelength decreases, and vice versa. The relationship between wavelength and wave frequency is shown in Figure 9.

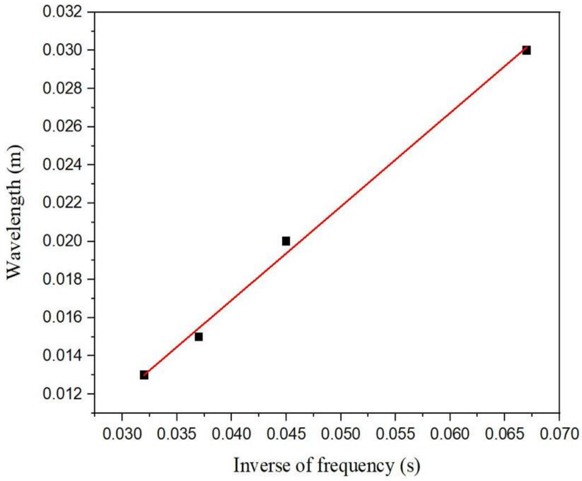


**Figure 9.** The graph shows the relationship between the inverse of frequency and wavelength.

In the graph, the wave speed could be calculated from the slope of the graph, which shows the relationship between wave frequency and wavelength. The wave speed value is (4.90±0.21) $10^{-1}$ $ms^{-1}$. The inverse frequency of the wave varied with wavelength, which shows that increasing the frequency from 15 Hz, 22 Hz, 27 Hz, and 31 Hz resulted in a decrease in wavelength. This relationship highlights how changes in frequency directly affect the wavelength of the wave. As the frequency increases, the wavelength becomes shorter, demonstrating the inverse relationship between these two wave properties.

**Table 4.** The value of wave frequency, wavelength, and the inverse of frequency.

| Wave frequency (Hz) | Wavelength (m) | Inverse of frequency (s) |
|---|---|---|
| 15 | 0.030 | 0.067 |
| 22 | 0.020 | 0.045 |
| 27 | 0.015 | 0.037 |
| 31 | 0.013 | 0.032 |

**b. Reflection**

The portable ripple tank set was tested to study the reflection of waves on plane waves. The portable ripple tank was tested to study the reflection of waves on plane waves, as shown in Figure 10. A reflector was placed inside the tank to observe how the waves reflect off its surface, demonstrating the principles of wave reflection.

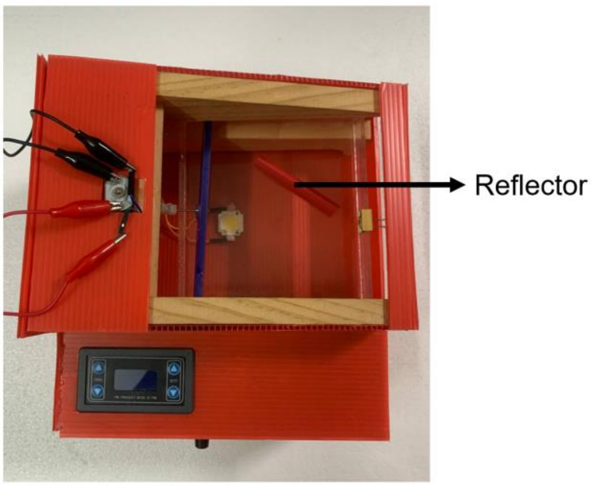


**Figure 10.** The portable ripple tank setup with a reflector is used to observe wave reflection and changes in wave direction.

According to the law of reflection, the reflected ray's angle equals the incident ray's angle relative to the surface normal (Ning, Sun, Wang & Cong, 2025). The plane reflector was used to reflect wavefronts and form clear patterns for observing wave behavior, including angles of incidence and reflection. Adjusting the reflector's position allowed exploration of different scenarios, such as specular and diffuse reflection, as shown in Figure 11.

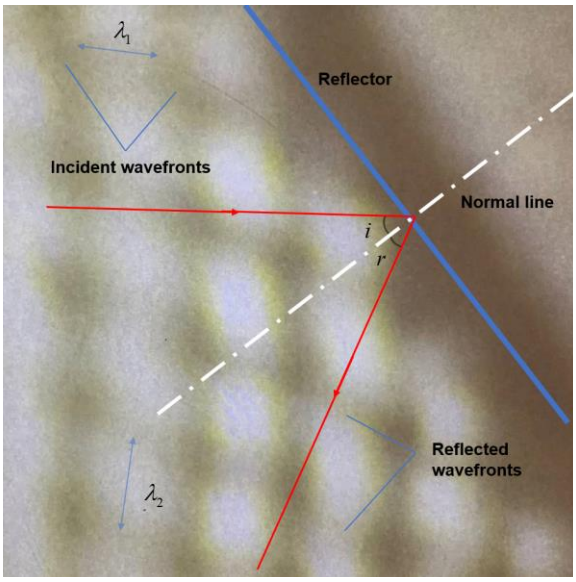


**Figure 11.** The reflection pattern of water waves shows the angles of incidence, i, and reflection, *r.*

The phenomenon of reflected waves only causes the wave direction to change, while other wave characteristics do not. The angle of incidence is equal to the angle of reflection, and this condition leads to a change in the direction of waves. Besides, the wavelength, frequency, and wave speed remained the same after the reflection of the wave because there was no change after the phenomenon of reflected waves occurred.

### c. Refraction

Refraction of waves refers to a shift in the direction of waves as they move from one medium to another, whether from a deep water region to a shallow water region or vice versa. The portable ripple tank set investigated wave refraction in plane waves. The perspex sheet with a trapezium shape was used to form the deep and shallow regions, creating a clear boundary for wave interaction as shown in Figure 12, allowing for the study of wave refraction.

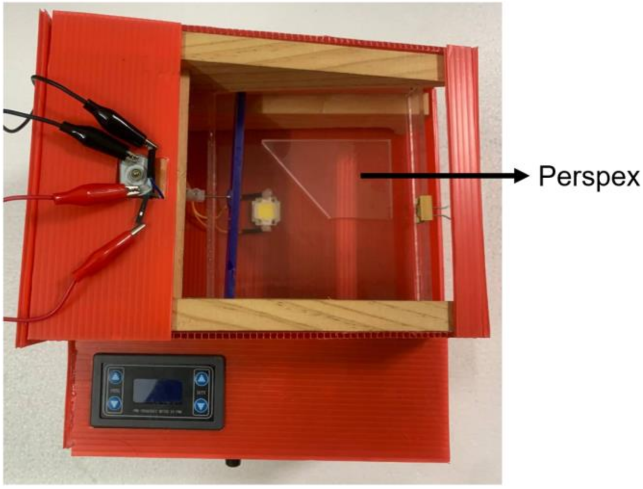


**Figure 12.** The portable ripple tank is set up with a perspex sheet to conduct a diffraction experiment.

This experiment has two conditions: deep water region to shallow water region and shallow water region to deep water region. These conditions allow students to study the phenomenon of refraction, observing changes in wave speed, wavelength, and direction as the waves transition between regions of different depths. The result of both conditions is shown in Figure 13.

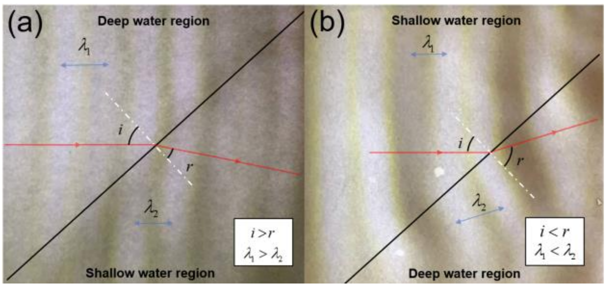


**Figure 13.** The refraction pattern of water waves after travelling from (a) deep to shallow region and (b) shallow to deep region.

The refraction of water waves affects various wave properties such as speed, wavelength, frequency, wave direction, and angles of incidence and refraction. In transitions from deep to shallow water regions, the incidence angle exceeds the refraction angle. In contrast, in transitions from shallow to deep water regions, the angle of incidence is less than the angle of refraction. This shift occurs because the wave propagation direction moves closer to or further from the normal. Additionally, water waves travel more slowly when moving from deep to shallow water and faster from shallow to deep water, influenced by the medium's properties. Depth plays a crucial role in determining wave speed over the water surface. Changes in wave speed also impact wavelength, as indicated by equation (2), where wave speed is directly proportional to wavelength. Consequently, when the wave speed increases, the wavelength also increases, and vice versa. This means wavelengths shorten when transitioning from deep to shallow water and lengthen when moving from shallow to deep water. While wave speed changes due to depth variations (Vedad, 2021). However, the wave frequency remains constant as the source's vibrations determine it, and the refracting medium's motion does not affect it.

**d. Diffraction**

The bending of waves around objects or corners is a phenomenon of waves known as diffraction. Wave diffraction is the spreading of wave energy perpendicular to the main direction of propagation (Konispoliatis & Mavrakos, 2021). Diffraction occurs when a wave passes through an aperture, changing direction as it enters a protected area. It can be demonstrated by placing small barriers in a ripple tank and observing how water waves pass around them, disturbing the water behind. The portable ripple tank was tested to study plane wave diffraction, as shown in Figure 14.

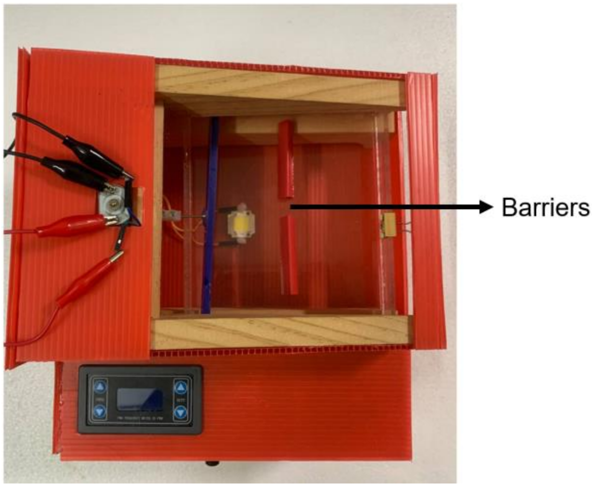


**Figure 14.** The portable ripple tank setup with barriers is used to observe the diffraction of waves.

The experiment demonstrated how waves change direction when encountering an obstacle or gap. The results showed clear diffraction patterns as the waves interacted with the barrier. This confirms the expected diffraction behavior. The pattern of diffraction is shown in Figure 15.

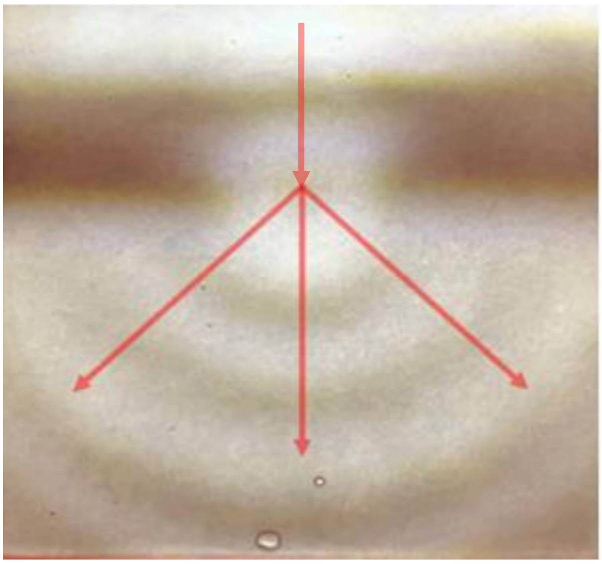

**Figure 15.** Diffraction pattern of water waves, showing the spreading of water waves after passing through an aperture.

The effect of the diffraction only involves the amplitude and direction of propagation. The amplitude of a wave is related to the amount of energy it carries. A high-amplitude wave carries much energy, or vice versa. The diffraction of water waves causes the value of the amplitude to decrease. This is because a wave expands over a larger area when it undergoes diffraction. The energy of a wave reduces as its area increases, and hence its amplitude also decreases. Besides, the direction of propagation also changes for water waves when they experience diffraction, as seen in Figure 10. This is because of its frontal spread, the wave travels from one direction to many after passing through a slit. The wave transmitted through the aperture spreads around and behaves like a point source of waves. However, no change in wavelength, frequency, or wave speed is caused by diffraction. The wave speed remained unchanged because the medium through which the wave traveled remained constant before and after the diffraction. Since wave speed is determined by the properties of the medium, such as its density, and these properties did not vary, the wave continued to propagate at the same velocity even after undergoing diffraction.

**e. Interference**

Wave interference will occur when two waves collide while moving across the same medium. Interference of waves is the superposition of two or more waves from a coherent source of waves. Two sources of waves are coherent when the frequency of both waves is the same and the phase difference is constant. The superposition of waves will produce constructive interference and destructive interference. Constructive interference occurs when two waves combine, amplifying each other and producing a more substantial wave. In contrast, destructive interference happens when two waves overlap to cancel each other out, leading to reduced or nullified amplitude. These wave interactions are fundamental to understanding various wave phenomena. The spherical dipper has been used to form an interference pattern. The experimental setup and interference pattern obtained are shown in Figures 16 and 17.

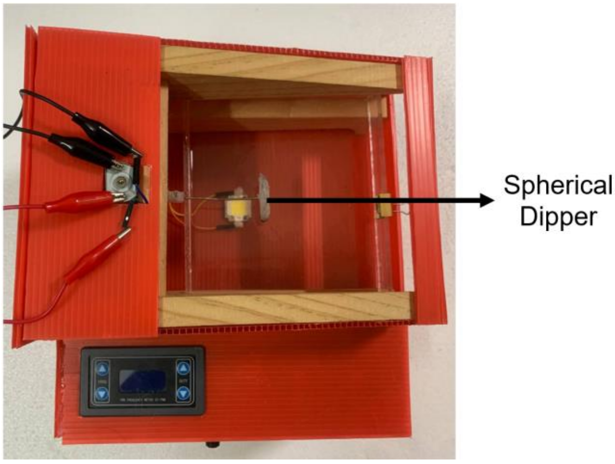


**Figure 16.** The spherical dipper generates two coherent sources for observing wave interference patterns.

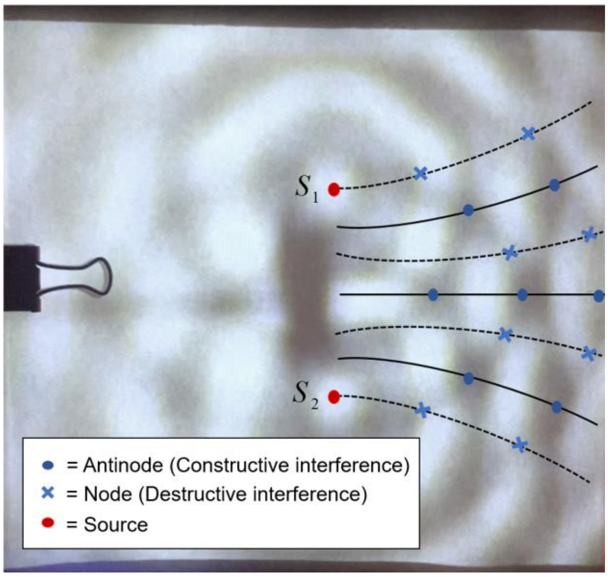


**Figure 17.** The interference pattern of water waves is generated by two spherical dippers, forming constructive (antinode) and destructive (node) interference.

The interference pattern forms distinct bright, dark, and grey areas, illustrating the principles of wave interaction. It is constructive interference for the bright and dark areas (Westhoff & Pusch, 2023; Choy, Chuan, Beng, Mustafa, & Ragavan, 2020). The bright area arises from constructive interference between two crests in superposition, increasing wave amplitude and intensity. Similarly, the dark area represents constructive interference between two troughs in superposition, where the waves combine to form a region of low intensity. On the other hand, the grey area manifests destructive interference, occurring when a crest and a trough are in superposition. In this case, the waves partially cancel each other out, reducing the overall amplitude and resulting in a more subdued, grey region. These interference effects are critical in demonstrating fundamental wave behavior and are central to understanding the principles of superposition, wave propagation, and energy distribution in wave phenomena. Through observation of these interference patterns, students gain a deeper and more comprehensive understanding of how waves interact and influence each other in various ways. They can explore how constructive interference occurs when wave crests or troughs align, leading to an amplified wave, and how destructive interference occurs when a crest meets a trough, resulting in partial or complete wave cancellation. By actively engaging with these phenomena, students develop critical thinking skills as they investigate the principles governing wave behavior. This hands-on exploration enhances their theoretical knowledge and allows them to visualize and internalize fundamental wave concepts meaningfully (Bezen & Bayrak, 2020). Furthermore, understanding wave interference has practical applications in various scientific and technological fields, including acoustics, optics, and even quantum mechanics, reinforcing wave dynamics' relevance in everyday life and advanced research.

The experiment using this portable ripple tank validates the theory of wave phenomena and characteristics by demonstrating how waves propagate through a specific medium and how properties such as wavelength, speed, and amplitude can be measured and analyzed empirically. This tool allows for direct observation of waves, thereby confirming the relationship between theoretical concepts and practical applications in understanding wave properties and the effects of varying parameters on the generated waves. This tool validation makes it a practical resource for educational and experimental purposes, providing a reliable method to visualize and study wave behavior.

**Phase 5: Evaluation**

Evaluation is an ongoing feedback process to gather general insights and assess the overall effectiveness of the project (Suratnu, 2023; KOÇ, 2020). Three experienced physics teachers with expertise in physics and teaching evaluated the portable ripple tank set. The effectiveness of the ripple tank was assessed based on their observations during lab sessions, where they used the experimental set in real classroom settings. Teachers A, B, and C, each bringing unique teaching styles and knowledge, provided valuable feedback on various aspects of the tank's performance. All the teachers voluntarily participate in the session; their characteristics are shown in Table 5.

**Table 5.** The teacher’s characteristics as a participant.

| Characteristic | Teacher A | Teacher B | Teacher C |
|---|---|---|---|
| Gender | Female | Female | Female |
| Educational qualification | Bachelor of Agricultural Engineering<br><br>Postgraduate Diploma in Education | Bachelor of Physics with Education | Bachelor of Electrical Engineering<br><br>Postgraduate Diploma in Education |
| Teaching experience | 20 years | 15 years | 15 years |

Three physics teachers have attempted to use the portable ripple tank and evaluated it after using it. The evaluation provided by the three physics teachers for the portable ripple tank has been summarized as shown in Table 6. Their insights offer valuable feedback on its effectiveness in teaching wave phenomena and supporting student learning.

**Table 6.** The teacher's evaluation of the portable ripple tank.

| Teacher | Evaluation |
|---|---|
| Teacher A | This ripple tank is portable and easy to take anywhere for activities, either in the laboratory or the classroom, because of its small size and light design, making it easy for teachers or students to use.<br>The two power modes on this portable ripple tank, direct current and battery, add portability advantages to the ripple tank. |
| Teacher B | An existing ripple tank in school is more costly than the portable one.<br>Schools can provide more ripple tanks so students can explore the phenomena and characteristics of waves. |
| Teacher C | The portable ripple tank is easier to construct because the construction uses materials and electronic components that are easy to find and cheap.<br>The portable ripple tank should be produced in greater numbers to help the community or school have more opportunities to learn about the learning characteristics and phenomena of waves efficiently. |

Therefore, with this innovation, the school can provide a portable ripple tank experimental tool to enhance the teaching and learning on waves so that the students can explore more independently. As a result of the lab session to test the portable ripple tank with the teachers, the use of portable ripple tanks is essential in schools because of their reasonable price and ease of use compared to conventional ripple tanks. This initiative can prepare our teachers to teach experiments effectively in the school to address the knowledge and understanding required to teach scientific skills (Gkioka, 2019).

All three teachers validated and gave a positive evaluation based on their experience using the portable ripple tank. Their feedback highlighted its effectiveness in demonstrating wave phenomena, improving student engagement, and supporting hands-on learning through ease of setup, portability, and clarity of wave patterns. The teachers praised its user-friendly design, enhancing lesson integration and concept understanding. Overall, they expressed confidence in its potential to support teaching and student learning outcomes in physics. The portable ripple tank was widely recognized for its significant impact on student engagement, as it provided an interactive and hands-on learning experience that deepened students' understanding of wave phenomena. Its practical application in the classroom allowed educators to demonstrate waves.

To summarize the practical benefits of the portable ripple tank, a structured comparison with conventional ripple tanks was conducted based on direct observations and teacher interviews. Firstly, in terms of cost, many teachers reported that conventional ripple tanks are prohibitively expensive and often beyond public schools' budgets. The prototype developed in this study is designed with a cost-effective approach, making it significantly more affordable than conventional ripple tank units.

Secondly, conventional ripple tanks are typically bulky and heavy on portability, requiring multiple people to move and a fixed laboratory space for operation. In contrast, the portable ripple tank is compact and lightweight, enabling teachers or students to carry and set it up independently. The dual power mode lithium-ion battery or DC adapter adds further flexibility for use in any classroom.

Thirdly, to address the issue with the hand stroboscope, which many teachers found difficult to use and unreliable in bright environments, the new ripple tank features an integrated digital stroboscope with adjustable LED frequency. This setup improves visibility and allows for clearer, more stable wave observations by projecting wave patterns from below the water tray onto a screen. This ensures consistent visibility even under bright ambient light conditions. The direct comparison between conventional and portable ripple tanks is shown in Table 7, highlighting the improvements achieved through this innovation.

**Table 7.** Comparison between conventional and portable ripple tank.

| Feature | Conventional Ripple Tank | Portable Ripple Tank |
|---|---|---|
| Size | Large | Compact |
| Portability | Requires multiple people to carry | Can be carried by one person |
| Power Source | DC power supply only | Dual mode: lithium-ion battery or DC adapter |
| Usability | Primarily used in laboratories only | Suitable for classrooms and laboratories |

## CONCLUSION

This study successfully fulfilled its objective of developing a portable ripple tank as an innovative and practical experimental tool to enhance the teaching and learning of wave phenomena and characteristics. Guided by the ADDIE instructional design model, the research systematically progressed from identifying the core challenges faced by physics teachers, namely the high cost, lack of portability, and poor observation clarity of traditional ripple tanks, to designing, prototyping, and evaluating a solution that directly addressed these limitations. The prototype was constructed using low-cost, recycled, readily available materials, resulting in a compact, lightweight design suitable for classroom and laboratory use. Integrating a digital stroboscope and a lithium-ion battery power system significantly improved usability and accessibility. The stroboscope enabled clear visualization of wave patterns, while the dual power source allowed for flexible use across various educational settings. A structured comparison between the conventional and portable ripple tanks highlighted substantial improvements in usability, size, power source flexibility, and portability. Through classroom implementation and practical demonstrations of key wave concepts, reflection, refraction, diffraction, and interference, the portable ripple tank provided a more engaging, hands-on learning experience. Teachers reported that the tool facilitated better conceptual understanding by allowing students to observe wave behavior in real time. Experimental results, such as measurable relationships between wave speed, frequency, and wavelength, further validated the educational value of the prototype. Evaluation by three experienced physics educators confirmed the tool’s practicality and effectiveness in teaching contexts. They emphasized its affordability, ease of setup, and ability to support interactive learning. Their feedback underscored the tool’s potential to expand access to high-quality experimental learning in schools with limited resources. In conclusion, the portable ripple tank developed in this study represents a meaningful advancement in physics education. Its affordability, portability, and improved visualization capabilities make it a practical and accessible tool for supporting deeper student understanding of wave mechanics. This innovation offers a more practical and engaging approach to teaching wave phenomena across various educational environments by addressing key limitations of conventional ripple tanks.

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