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Problem-Based Learning for Sustainable Hydrology Education: Develop a Campus Rain-gauge Networks for Rainfall Monitoring

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Abstract. Sustainable water management requires future professionals to possess not only theoretical knowledge but also practical skills in environmental monitoring. This study investigate the integration of problem-based learning (PBL) and experiential field activities through the development of a campus-based rain gauge network constructed and operated by undergraduate geography students. Students were challenged to design, install, and manage low-cost rainfall monitoring stations across selected micro-catchments within the university campus. Rainfall data were collected over several weeks and analysed to identify spatial rainfall patterns and basic hydrological responses. All evaluated learning outcomes recorded high mean scores ranging from 3.89 to 3.95 on a four-point Likert scale, indicating strong student agreement regarding the effectiveness of the PBL-based experiential learning approach. Findings indicate significant improvements in students' hydrological literacy, field data collection competency, and understanding of rainfall-runoff processes at the local scale. The use of simple and low-cost rain gauges demonstrates the potential for scalable and inclusive hydrology education approaches, particularly in institutions with limited access to advanced monitoring equipment. This study highlights the effectiveness of integrating PBL with experiential hydrological monitoring to strengthen sustainability oriented water education.

Keywords: Problem-based learning, hydrology education, experiential, water sustainability



1. Introduction

Hydrology education plays a crucial role in developing students' understanding of water systems, particularly in the context of increasing climate variability, urbanization, and water resource challenges. Traditional teaching approaches in hydrology are often theoretical and lack opportunities for students to engage with real-world data and field-based experiences (Georgakakos, 2024; Lin et al., 2010). This limitation can hinder students' ability to fully grasp dynamic hydrological processes such as rainfall variability, runoff generation, and catchment response. Therefore, there is a growing need to adopt innovative and experiential learning approaches that bridge the gap between theory and practice (Ruddell & Wegener, 2015). Problem-Based Learning (PBL) has emerged as an effective pedagogical approach that promotes active learning, critical thinking, and problem-solving skills (Nemakhavhani, 2024). In the context of hydrology education, PBL allows students to engage directly with environmental data, investigate real-world issues, and develop practical solutions (Mutanga, 2024).

By integrating hands-on activities with inquiry-based learning, students are better equipped to understand complex hydrological systems and their relevance to sustainable water management. One promising approach to enhance hydrology learning is the development of a campus-based rain gauge network. The implementation of Problem-Based Learning (PBL) in this study follows a structured learning framework that emphasises progressive knowledge construction through real-world problem engagement (Nemakhavhani, 2024). Initially, students are presented with a contextual hydrological problem, such as understanding rainfall variability within a campus micro-catchment. Subsequently, students identify the knowledge and skills required to address the problem, including rainfall measurement techniques, data recording, and hydrological interpretation (Georgakakos, 2024). Through guided inquiry and hands-on activities, students then apply their knowledge by designing, constructing, and operating rain gauges, followed by analysing the collected data to derive meaningful hydrological insights. This iterative process encourages active learning, critical thinking, and the integration of theory with practice. Figure 1 was the framework applied in this study, where students are first introduced to a real-world hydrological problem, followed by identification of required knowledge, and finally the application of learned concepts through hands-on rain gauge activities. Rainfall is a fundamental component of the hydrological cycle, influencing surface runoff, infiltration, and water availability (Khatakho et al., 2016; Gires 2018). However, students often rely on secondary datasets, limiting their exposure to data collection processes and spatial variability of rainfall (Gires, 2018). Establishing a network of rain gauges across a university campus provides an opportunity for students to collect, analyse, and interpret real-time rainfall data within a micro-catchment environment (Wegener et al., 2010). This study proposes the integration of Problem-Based Learning with the development of a campus rain gauge network as an experiential learning tool for sustainable hydrology education. Through this approach, students are involved in the design, installation, monitoring, and analysis of rainfall data, enabling them to explore spatial and temporal rainfall patterns and their implications for hydrological processes.

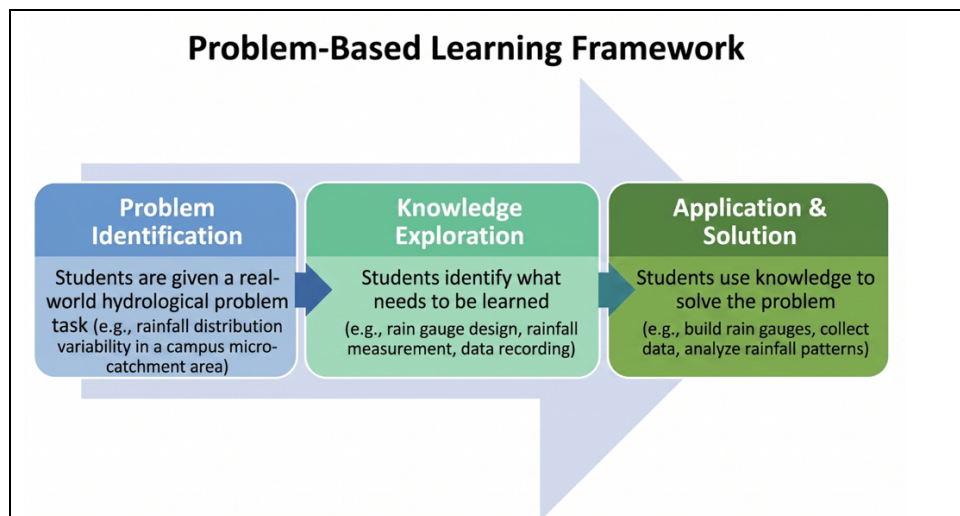


Figure 1. PBL framework adopted in this study

The initiative not only enhances students' technical competencies in data collection and analysis but also fosters environmental awareness and sustainability-oriented thinking. By embedding real-world hydrological monitoring within a PBL framework, this study aims to demonstrate how low-cost, scalable, and context-based educational innovations can improve hydrological literacy. The findings contribute to the advancement of sustainable hydrology education, particularly in institutions with limited access to advanced monitoring technologies, and support the broader goal of developing future professionals capable of addressing water-related challenges.

2. Material and Methods

Rain gauges are essential instruments for measuring rainfall distribution within a given area. In conventional learning settings, students often rely on secondary data from agencies such as Department of Irrigation and Drainage (DID) or MetMalaysia, limiting their understanding of real-world data collection processes. This study addresses this gap by providing hands-on experience through the construction and use of rain gauges, enabling students to directly measure rainfall, particularly in ungauged catchments where no official monitoring stations are available. This study was conducted within the Sultan Azlan Shah Campus (KSAS), Universiti Pendidikan Sultan Idris (UPSI), Tanjong Malim, Perak, Malaysia. The campus represents a small urbanized catchment characterized by a combination of built-up areas, open spaces, and vegetated surfaces. Several monitoring locations were selected across the campus to enable the observation of rainfall variability within different micro-environmental settings (Figure 2). The study adopted a quantitative field-based design integrated with a Problem-Based Learning (PBL) framework. Undergraduate geography students were divided into several groups, with each group assigned the responsibility of constructing, installing, and managing a rain gauge at a designated location within the campus. This approach allowed students to actively participate in real-world hydrological monitoring while applying theoretical knowledge in a practical context.

A campus-based rain-gauge network was developed, consisting of multiple rain gauges distributed across selected locations. The placement of each rain gauge was determined based on site suitability criteria, including minimal obstruction from surrounding buildings or vegetation, adequate exposure to rainfall, accessibility for daily observation, and safety of installation (Kidd

et al., 2016) This distributed setup enabled the collection of rainfall data from multiple points, allowing for the analysis of spatial variability within the campus.



Figure 2. Several monitoring locations were selected across the campus.

Each rain gauge was constructed using low-cost and locally available materials such as plastic bottles, funnels, PVC pipes, and protective mesh. The funnel diameter was standardized at 12 cm to ensure consistency in measurement across all monitoring stations. The collected rainwater was measured in millilitres (ml) and subsequently converted into rainfall depth in millimetres (mm) using a standardized calculation method based on the catchment area of the funnel. The cross-sectional area was determined using the formula $A = \pi r^2$, where π is approximated as $22/7$ and r is the radius of the funnel. Figure 3 shows Sketch of the group's rain gauge showing the funnel, plastic bottle, and supporting wooden structure. Rainfall data were collected over a period of 14 consecutive days, from 17 April to 30 April 2025, through daily manual observations. Each group recorded rainfall measurements at their assigned station using a standardized data recording format to ensure consistency and comparability across all locations. The data collected from all stations were then compiled into a unified dataset for further analysis. The rainfall dataset was analysed using descriptive statistical methods to examine both temporal and spatial variations in rainfall distribution. The analysis included total rainfall accumulation, daily rainfall variation, and comparison of rainfall values between different monitoring locations. This enabled the identification of localized rainfall patterns and potential differences in rainfall distribution across the campus micro-catchments.

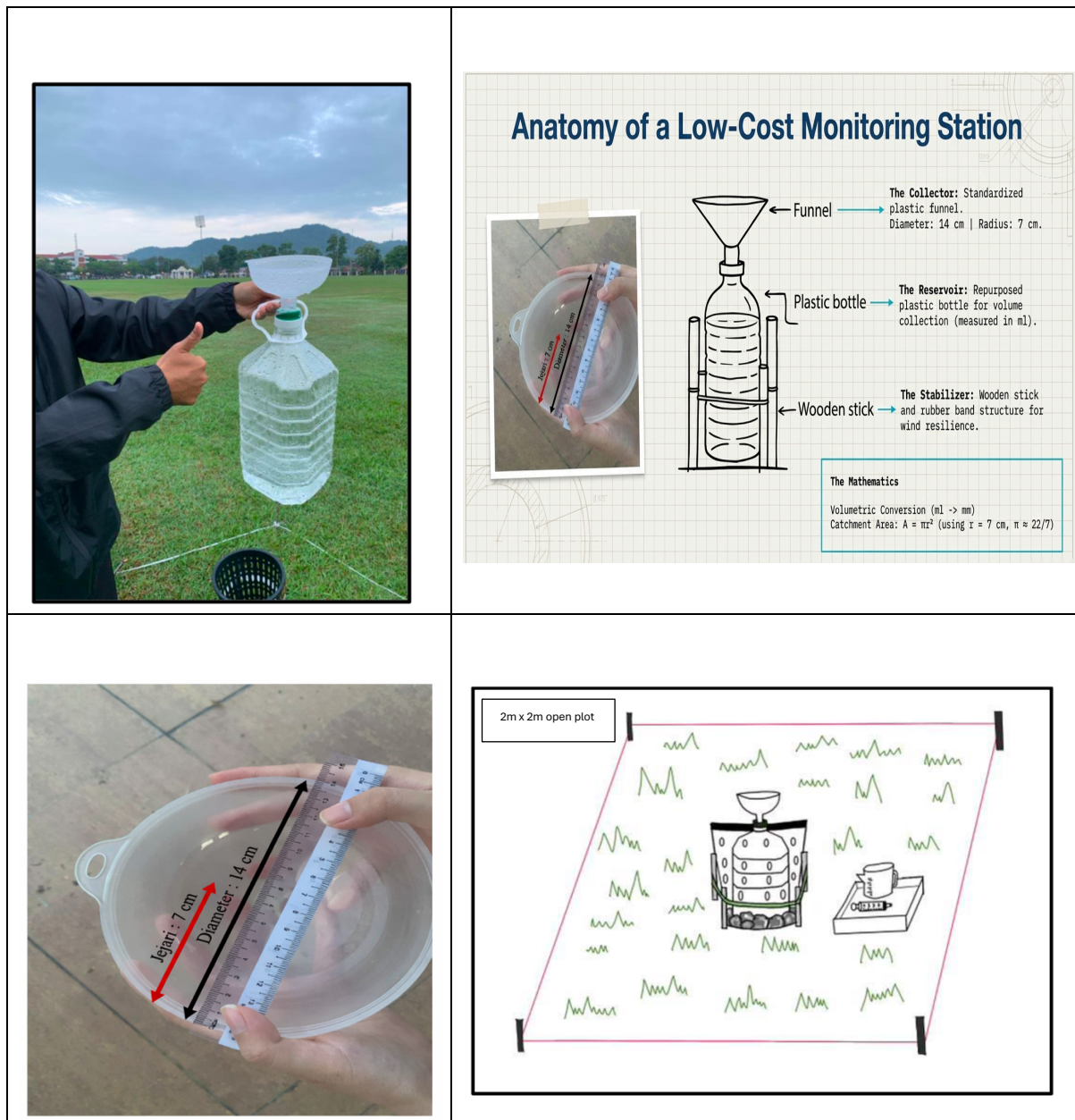


Figure 3. Measurement of the funnel showing the diameter (14 cm) and radius (7 cm).

The implementation of the rain-gauge network was embedded within a Problem-Based Learning framework, where students were required to address practical challenges such as selecting appropriate monitoring sites, ensuring data accuracy, and interpreting rainfall variability in relation to hydrological processes (Smith & Jone, 2015; Srivasta, 2009). This approach facilitated the integration of theoretical hydrology concepts with real-world environmental observations (Zhang & Ma, 2023). To evaluate the effectiveness of the learning approach, student performance and learning outcomes were assessed using pre- and post-activity tests, reflective learning journals, and group-based hydrological analysis tasks. These assessments provided insights into

improvements in students' hydrological literacy, field data collection skills, and understanding of rainfall–runoff processes within a localized urban catchment. Rainfall data collected from the student-built monitoring stations were compiled and analysed to identify spatial variations in rainfall distribution across the campus micro-catchments. To ensure data reliability, all groups followed a standardized rain-gauge construction protocol, uniform measurement procedures, and consistent data-recording formats. Regular supervision and data verification were conducted throughout the monitoring period to minimize measurement errors and ensure consistency among stations. These assessments provided insights into improvements in students' hydrological literacy, field data collection skills, and understanding of rainfall–runoff processes within a localized urban catchment.

3. Results and Discussions

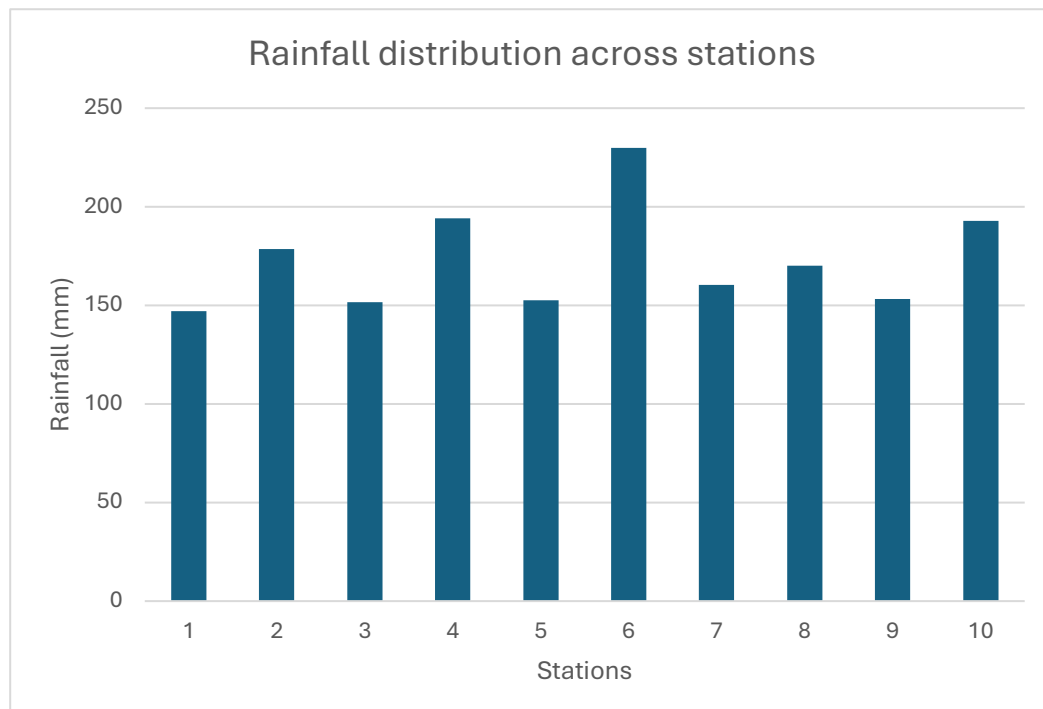
3.1 Rainfall Monitoring

Table 1 presents the calculation and measurement of rainfall obtained from manual data collection using a student-constructed rain gauge. The dataset shows the conversion of collected rainfall from millilitres (ml) to cubic centimetres (cm³), and subsequently into rainfall depth (mm), demonstrating the complete measurement process. The results indicate variability in daily rainfall, with the highest value recorded on Day 4 (52.60 mm) and no rainfall observed on several days (Day 11 and Day 13). The total accumulated rainfall during the observation period was 146.94 mm. This dataset highlights the effectiveness of manual gauging in capturing real-time rainfall variability and supports students' understanding of rainfall measurement and hydrological data analysis. Figure 4 shows the average rainfall across the 10 stations, calculated using the arithmetic mean method, was 173.04 mm. This value represents the areal precipitation based on the assumption that rainfall is uniformly distributed across the study area. The computed average rainfall of 173.04 mm provides an estimate of areal precipitation across the study area using the arithmetic mean method. This method assumes that all rain gauge stations contribute equally to the overall rainfall, making it suitable for areas with relatively uniform rainfall distribution and evenly spaced stations. The findings were obtained through manual rainfall gauging conducted by students using a self-constructed rain gauge.

However, the observed variation in rainfall values, ranging from 146.94 mm to 230 mm, indicates some degree of spatial heterogeneity. The notably higher rainfall at Station 6 suggests localized rainfall intensification, which may not be fully captured by the arithmetic mean approach. As a result, while the calculated average provides a general representation of rainfall conditions, it may underestimate or overestimate actual precipitation in specific locations. Despite this limitation, the arithmetic mean method remains a practical and widely used approach for estimating areal precipitation, particularly in small catchments or preliminary hydrological analysis where station distribution is relatively consistent (Bayraktar et al., 2005). The relatively moderate spread of rainfall values suggests that the arithmetic mean method is reasonably applicable in this case, although more advanced methods such as Thiessen polygon or isohyet analysis may provide improved spatial representation (Bayraktar et al., 2005).

Table 1. Calculation and measurement of rainfall obtained from manual data collection

Day	Date	Total Rainfall (ml)	Rainfall (mm)
1	17/4/2025	410	26.62
2	18/4/2025	60	3.9
3	19/4/2025	9	0.58
4	20/4/2025	810	52.6
5	21/4/2025	70	4.55
6	22/4/2025	220	14.29
7	23/4/2025	84	5.45
8	24/4/2025	25	1.62
9	25/4/2025	10	0.65
10	26/4/2025	5	0.32
11	27/4/2025	0	0
12	28/4/2025	80	5.19
13	29/4/2025	0	0
14	30/4/2025	480	31.17
Total		2263	146.94

**Figure 4.** The average rainfall across the 10 stations, calculated using the arithmetic mean method.

3.2 Student Learning Outcomes from PBL Approach

Figure 5 shows the comparison of mean hydrological literacy scores before (pre-test) and after (post-test) the PBL-based hands-on rain gauge activity. The results indicate a substantial increase from 47% to 83%. The results indicate a substantial improvement in students' hydrological literacy following participation in the PBL-based hands-on rain gauge activity. The overall mean literacy score increased from 47% in the pre-test to 83% in the post-test, representing a mean improvement of 36%. This increase reflects the average performance of 100 students across all assessment items. In terms of domain-specific performance, the greatest improvements were observed in technical competency, particularly in unit conversion, rainfall measurement reading, and systematic data recording. Conceptual understanding also showed significant improvement, with students demonstrating better knowledge of rain gauge function, rainfall units, and the importance of funnel dimensions. Analytical understanding, including rainfall-runoff relationships and interpretation of local rainfall variability, also improved, although to a slightly lesser extent compared to technical skills. Overall, the findings suggest that students not only acquired factual knowledge but also developed practical skills and the ability to interpret hydrological processes based on real data collected during the activity. The process of constructing, positioning, and operating the instrument provided opportunities for repetitive practice, which enhanced their ability to read measurements accurately, perform unit conversions, and record data systematically. These findings suggest that hands-on activities are particularly effective in strengthening procedural knowledge and field-based skills.

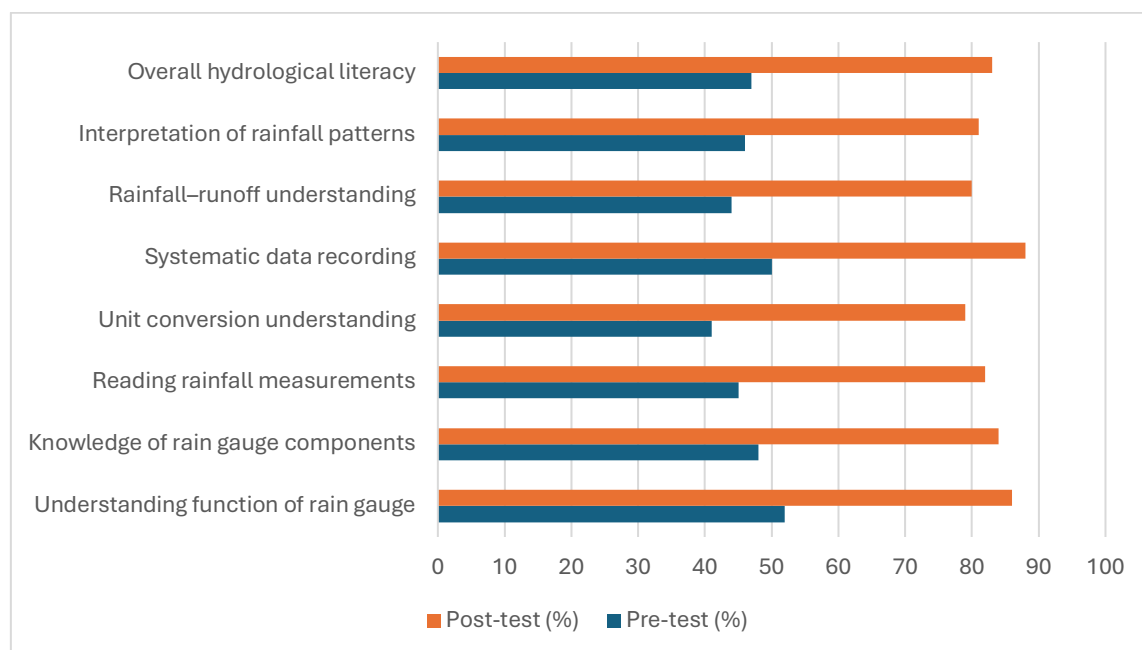


Figure 5. Mean hydrological literacy scores before (pre-test) and after (post-test) the PBL-based hands-on rain gauge activity

Although improvements in analytical understanding were slightly lower compared to technical skills, students demonstrated a clearer ability to relate rainfall data to runoff processes and local hydrological behaviour. This indicates that the activity successfully facilitated the transition from data collection to data interpretation. The use of real, student-generated data likely contributed to this improvement by providing a concrete basis for understanding rainfall variability and its implications for surface runoff at the micro-catchment scale. The organisation of students into 10 groups supported collaborative learning and problem-solving, which are key elements of the PBL approach. Through group discussions and shared tasks, students were able to exchange ideas, address practical challenges, and develop a deeper understanding of the activity. This collaborative environment likely contributed to increased confidence and engagement, as reflected in the improved performance across all domains (Hussein, 2021). The findings highlight the potential of low-cost, self-built rain gauges as effective teaching tools in hydrology education. The use of simple and accessible materials allows the activity to be implemented in various educational settings, including institutions with limited resources. Furthermore, the integration of PBL and experiential learning aligns with sustainable education practices by promoting active learning, environmental awareness, and practical skill development.

4. Conclusion

This study demonstrates that integrating problem-based learning with hands-on rain gauge construction is an effective approach for enhancing hydrological literacy among undergraduate students. The activity improved students' conceptual understanding, technical competency, and analytical skills related to rainfall measurement and rainfall-runoff processes. The findings highlight the importance of experiential learning in bridging the gap between theory and practice in hydrology education. The use of low-cost instruments provides a scalable and sustainable approach that can be implemented across various educational contexts. This approach also contributes to the development of environmentally aware and skilled graduates, supporting broader goals in sustainable water resource management.

5. Acknowledgement

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