Journal of Turkish Science Education, 2025, *22*(4), 677-702.
DOI no: 10.36681/tused.2025.034

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

Supporting eighth-grade pupils' understanding of hydrostatic pressure with inquiry-based activities

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ABSTRACT
This study aims to facilitate and implement inquiry-based exercises in the domain of hydrostatic pressure within the subject of physics education. The design research method was used to support eighth-grade pupils at Palembang State Middle School by developing inquiry-based activities on hydrostatic pressure. Three stages–experimental preparation, classroom experiments (pilot experiments and teaching experiments, and retrospective analysis–were carried out to formulate pupil learning trajectories. Pupils were expected to form the hypothesis that the dam walls are designed to increase the thickness of deeper wall or dam. They then created and conducted an experiment using appropriate tools and materials. The data collected were graphed and the graph was used to determine whether the hypothesis had been proven true. Finally, pupils applied their understanding of hydrostatic pressure and to given problems. Findings demonstrated significant improvements in pupils' conceptual understanding, experimental skills, and problem-solving abilities. Generally, students were able to accurately describe the relationship between hydrostatic pressure and the depth and density of the liquid, as evidenced by their correct interpretation of experimental data and graphical representations. The results also can be used to implement inquiry-based activities with a broader planned learning trajectory, and as a pioneer of further research across different learning contexts.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received:
31.12.2024
Accepted:
01.05.2025
Available Online:
27.11.2025

KEYWORDS:
Educational design research, hydrostatic pressure, inquiry-based activities, learning trajectory.

To cite this article: Siahaan, S. M., Ismet, I., Soeharto, S., & Patriot, E. A. (2025). Supporting eighth-grade pupils' understanding of hydrostatic pressure with inquiry-based activities. *Journal of Turkish Science Education, 22*(4), 677-702. http://doi.org/10.36681/tused.2025.034

Introduction

Hydrostatic pressure is one of the topics in junior high school physics. Learners study the concept of pressure on liquids and the factors influencing it. Many have difficulty understanding this concept (Donkor Taale, 2011; Susman et al., 2008; Loverude et al., 2003; Zhou et al., 2019). Many attempts have been made to help pupils understand this topic centred on the teacher explaining the factors that affect the pressure in liquids, including the deeper the funnel entering the water inside the breaker, the different fluids are used differs from h1 for funnel-to-breaker depth, depending on the density, pressure increasing with depth, and pressure at any depth being the same in all directions, but increasing with density.

Previous studies have shown that hydrostatic pressure and buoyancy are difficult for learners at all levels, and many have misconceptions (Çepni et al., 2010; Chen et al., 2013; Radovanović & Sliško, 2013; Saputra et al., 2019; Soeharto, 2021). These misconceptions include objects floating in water because they are lighter than water, or objects sinking in water because they are heavier than water, the shape of the container and the amount of liquid affecting hydrostatic pressure, and fluid pressure only applying downwards (Pratiwi, 2013; Ramirez, et al., 2021;Saputra et al., 2019). Misconceptions occur because pupils obtain the wrong initial concept from the community, misunderstanding the teacher's explanation, and not being trained to find the concept of pressure directly and actively (A. C. & S. S., Edie, 2015; Syaiful, 2017; Wen et al., 2020).

Experiments or direct observations have been used to help pupils gain a deeper understanding of the concept of hydrostatic pressure and reduce their misconceptions (Keselman, 2003; Wenning, C.J., 2011; Jauhariyah et al., 2018). Using an experiment or mini project can enhance understanding in learning science (Hakim et al., 2016). Inquiry-based learning has been proven to improve understanding in science learning (Antonio & Prudente, 2021). Inquiry-based learning is a learning strategy in which learners follow inquiry methods and practices similar to those of professional scientists to construct knowledge (Shanmugavelu et al., 2020). This can be defined as the process of constructing some hypotheses, and testing them by conducting experiments and making observations (Bell et al., 2010). In the literature, the investigative process generally begins with asking questions and generating hypotheses, followed by an investigative process that ends with conclusions and evaluations (Hmelo-Silver et al., 2007; Murphy et al., 2018; Said et al., 2021). Making predictions is reformulating the hypothesised relationships between variables in such a way that it becomes clear how changes in the independent variable affect the dependent variable, for example using 'if- then' statements (De Jong & Van Joolingen, 1998). In this study, it is hoped that there will be an inquiry phase, making hypotheses, making experimental designs, conducting experiments, analysing data and explaining the results as an indication of following the inquiry approach.

Writing clear learning objectives is essential for effective teaching (Marzano, R.J., 1998). The success of a science lesson is inseparable from a teacher’s ability to plan lessons before teaching (Ramadhanti. P., 2015). This is consistent with what Hmelo-silver et al. started with Rutten et al., (2016) that the importance of this learning objective is to prevent a shift of inquiry learning away from the teaching discipline as a body of knowledge. Both the learning process and the content require adequate consideration. Combining an inquiry approach with concrete goals related to learning content implies that the environment in which learning occurs resembles the context in which it is likely to be used. One of the main obstacles to applying the inquiry learning model is that teachers need to adapt their role appropriately, and that the learning objectives associated with Bloom's taxonomy level require teachers to take on a less directive and more supportive role (Urhahne et al., 2010; Pietarinen et al., 2021). In this study, we used the learning trajectory to help school learners learn about liquid pressure using an inquiry-based learning model. The purpose of this research was to produce a learning trajectory that can assist pupils in learning about the pressure of liquids using an inquiry-based learning model.

Problems in Understanding Hydrostatic Pressure Concepts in Science Education

The majority of junior high school pupils struggle with comprehending abstract scientific concepts and solving related problems. Hydrostatic pressure as physics concept is a particularly challenging topic for pupils to grasp. To effectively learn the concept of hydrostatic pressure, they require assistance in constructing the foundational knowledge that underpins the idea (Berek et al., 2016). But many still have alternative conceptions or misconceptions (Pratiwi et al., 2019; Maknun, 2020).

Misconceptions can be owned by students when they gain knowledge about an event based on that knowledge; they formulate a naïve theory about the mechanisms of natural processes (McDermott, 1984). Some of the difficulties in understanding physics concepts are caused by several things, including difficulty interpreting mathematical equations and tending to use theories in explaining physical phenomena tend to use naïve theories in explaining physical phenomena (Loverude et al., 2003; Goszewski et al., 2013).

The understanding obtained is limited to the pressure that exists in a liquid is the same without considering the density of the liquid. The application of the hydrostatic pressure equation related to atmospheric pressure is still poorly understood; learners experience problems in the concepts of vacuum space and having air. Most assume that hydrostatic pressure is inversely proportional to the area of the fluid container; therefore, the larger the container area, the smaller the hydrostatic pressure. In many contexts they equate pressure with density (Tuada et al., 2023).

Inquiry-based Activities in Physics Learning

A learning model that is based on the nature of physics and provides opportunities for students to conduct investigations/experiments to form knowledge/physics concepts is needed. A guided inquiry learning model is one of the learning models that emphasises the science process skills, thinking skills, and scientific inquiry. The syntax of inquiry- based activities learning, according to Tekin and Muştu (2021), is orientation, formulation of problems, formulation of hypotheses, collecting data, testing hypotheses, and formulating conclusions. The advantage of the model is that the teacher does not just let go of the activities carried out by the pupils, so that pupils who think slowly can still follow the activities being carried out. Learning using inquiry-based activities can build learners into individuals who can access information and understand where the information is obtained. The worksheet used an inquiry- based learning model which is one of the factors that can achieve the expected learning goals.

The inquiry learning model can help students find and use various types of information and ideas to increase their knowledge of a problem or issue (Santosa, 2014; Frågåt et al., 2021). In other words, the inquiry learning model is a learning model involves learners fully in the learning process, can investigate existing problems, and find their own solutions to these problems. The advantages of implementing the inquiry-based learning model are as follows: (1) Can form and develop "self-concept" in students, so that they can better understand basic concepts and ideas. (2) Helps in using memory and transferring to new learning process situations. (3) Encourage learners to think and work on their own initiative, and be objective, honest, and open. (4) Encourage learners to think intuitively and formulate their own hypotheses. (5) Giving intrinsic satisfaction. The learning process was stimulating. (6) Can develop individual talents or skills. (7) Gives learners freedom to learn on their own. (8) Learners can avoid traditional learning methods (9) Can give learners enough time. Meanwhile, the disadvantages of applying the inquiry-based learning model are as follows: (1) It is difficult to control student activities and success. (2) It is difficult to plan learning because it collides with students' learning habits. (3) Sometimes, in implementing it, it takes a long time to make it difficult for teachers to adjust it to the predetermined time. (4) As long as the criteria for learning success are determined by students' ability to master the subject matter, this strategy is likely difficult to implement.

Relevant Studies in Indonesia

Several relevant studies have been conducted by Verawahyuni (2022), who reported on teacher performance in implementing laboratory-based guided inquiry with the main goal of reducing the number of misconceptions about static fluid material. Data on implementation, learning quality, and pupil activities were collected using observation and documentation techniques. The number of MK ? students was determined on the basis of the results of the conception test on static fluid material before and after the action. CAR ? was conducted at the junior high school level in Samarinda with the source of teacher observations, the learning process in class, and eighth grade pupils. The data were analysed descriptively. Rahmawati et al. (2018) know that students' concept understanding is taught by guided inquiry-based learning and conventional learning. The results of the study showed that the average number of classes that used guided inquiry-based learning was 78.44, while the number of classes that used conventional learning was 65.16, Based on this data, the guided inquiry model is an effective learning model used to improve pupils' concept understanding. Wardani et al. (2017) investigated the effect of inquiry-based laboratory activity by comparing the inquiry and non-inquiry laboratory activity in terms of conceptual understanding among junior high school pupils in the topic of lights and optics. The effectiveness of this method was also investigated for both male and female students. The method used in this research was a quasi-experiment that used two classes, where one class was randomly selected as the experimental class and the other as the control class. Dewi et al. (2019) had research result that student repeatedly have difficulties in understanding complex physics concepts, such as fluid dynamic concept. This occurred because the students' conceptual understanding was low, indicating a poor student mental model.

Research Questions and Study Significance

The main purpose of this study is to facilitate and implement inquiry-based exercises in the domain of hydrostatic pressure within the subject of physics education To achieve this purpose, we formulated two research questions as below:

1. How does the inquiry-based learning trajectory support eighth-grade pupils in understanding hydrostatic pressure and addressing common misconceptions?
2. What are the challenges and improvements observed in pupils' conceptual understanding, experimental skills, and problem-solving abilities through the implementation of inquiry-based activities?

The significance of this study lies in its contribution to enhancing pupils' conceptual understanding of hydrostatic pressure through an inquiry-based learning approach. By designing and implementing a structured learning trajectory, this study provides a framework for fostering scientific reasoning, critical thinking, and problem-solving skills among eighth-grade students The findings offer valuable insights into how inquiry-based activities can effectively address common misconceptions and improve pupils' ability to relate theoretical concepts to real-world applications, such as dam construction. Additionally, this study serves as a reference for educators in developing more engaging and student-centred instructional strategies, ultimately supporting the advancement of physics education. Moreover, the research contributes to the broader field of science education by demonstrating the impact of inquiry-based learning on learners' experimental skills and conceptual development, offering potential for adaptation across different learning contexts.

Methods

Research Design

This study is qualitative research that uses educational design research. Design research is a systematic and iterative methodology commonly used in education and other fields to develop and improve educational interventions, instructional materials, and learning environments. There were three stages: experimental preparation, classroom experiments (pilot experiments and teaching experiments), and retrospective analysis.Five activities were observed in performing learning trajectories using an inquiry-based learning model: understanding and constructing the concept, making the experimental design, conducting the experiment, making graphs, and solving related problems.

Participants

The participants in this study were purposefully selected to evaluate the impact of the educational intervention on a diverse cohort of eighth-grade pupils from a selected school in Palembang. Initially, the study involved five groups comprising a total of 30 students. Following the completion of the learning process, a rigorous selection process was undertaken to identify participants for data analysis. This process ensured balanced representation across gender and academic backgrounds, resulting in the selection of six pupils for the study. Prior to their participation, informed consent was obtained, and strict adherence to ethical standards was maintained, including the protection of participant privacy and data confidentiality.

Instrument

The developed supports the inquiry-based activities developed in this study and the instruments used to evaluate student activity sheets (SAS), interview sheets, field notes, Hypothetical Learning Trajectory (HLT), and digital books. The SAS are structured instructional materials designed to guide students through the inquiry-based learning process. These sheets serve as a framework for engaging learners in various learning activities, including hypothesizing, designing experiments, conducting investigations, collecting and analysing data, and drawing conclusions. The SAS are developed to facilitate step-by-step exploration of hydrostatic pressure concepts, helping learners actively construct knowledge through hands-on experiments and problem-solving tasks. Content validity of all instruments was assessed by two physics education lecturers to ensure the credibility, accuracy and quality of the content. This validation process aimed to confirm that the instruments effectively measure the intended constructs and align with the objectives of the study.

Data Analysis

In a design study employing a qualitative research approach, data analysis was centred on qualitative data collected throughout the research process. The data analysis involved a systematic examination focusing on open-ended survey responses and observational notes. The interpretation of qualitative data was constructed based on the activities in the Results and Discussion section. This analysis is carried out in alignment with the research questions or objectives, allowing for the exploration of complex, context-specific issues and providing rich, nuanced insights that inform the design and refinement of educational interventions or innovations in response to research findings. The iterative process in learning activities analysis supports ongoing reflection, refinement, and in-depth exploration of participants' experiences and perspectives, contributing to the enhancement of educational practices and the body of knowledge in the field.

Procedure and Data Collection

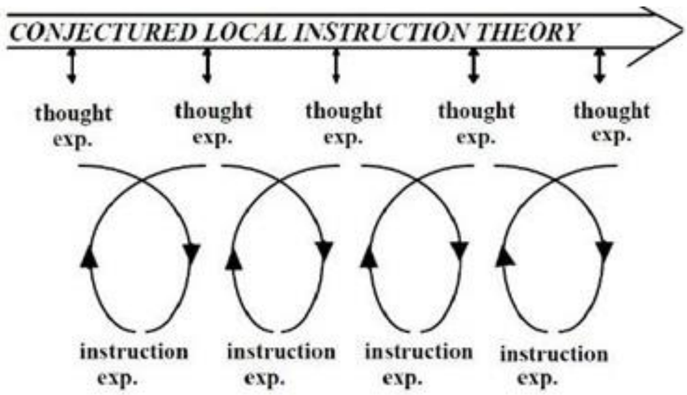
There were three stages: experimental preparation, classroom experiments (pilot experiments and teaching experiments), and retrospective analysis. In experimental preparation, researchers conducted problem identification, literature review, and design of the educational intervention and evaluation. Inquiry-based activities were developed in this study, and the instruments used to evaluate student activity sheets (SAS), interview sheets, field notes, Hypothetical Learning Trajectory (HLT), and digital books to collect initial qualitative data. In classroom experiments, teaching experiments were carried out. According to Gravemeijer (2004), the purpose of a teaching experiment is to test and raise suspicions about the Local Instructional Theory (LIT) developed at an early stage and to develop an understanding of how it works.the sequence of activities that were conducted in the early stages was carried out in the classroom in two cycles. The first cycle was conducted as a pilot study.

A pilot was conducted mainly to adjust the content and sequence of activities and improve them to obtain a better design for the next cycle, namely, the teaching experiment. The second cycle was carried out as the actual teaching process in which the sequence of activities was carried out in the classroom. The science content in the teaching trial stage in these two cycles remained the same, and in the second cycle, a revision was made from the first cycle. During the teaching experiment, the conjecture (guessing) of students' strategies and thinking can be developed for further learning in accordance with the characteristics of interventionist design research.

Retrospective analysis entailed gathering, scrutinising, and pondering data acquired from classroom experiments. Scholars have scrutinized these data to gauge the efficacy and influence of educational interventions within authentic learning environments. By meticulously assessing the data, they pinpointed recurring themes, tendencies, and valuable insights that shed light on the effectiveness of the intervention and potential areas for enhancement. Additionally, this phase encourages self-reflection within the research process, aiding researchers in making informed choices for future rounds of research and simplifying the process of documenting and disseminating discoveries to the community.

Figure 1

Argumentation skills score of PSTs



*Note.** (Gravemeijer, K. et al., 2006)

Findings

This research produced a learning trajectory on learning material on pressure on liquids in eighth-grade students by using the inquiry learning model and a scientific approach. In this chapter, the researcher describes all data obtained from each stage of the research. Three stages were used in this study: (1) preliminary design, (2) teaching experiment, and (3) retrospective analysis. The preliminary design is the first stage in this research, which is the research preparation stage (preparing for the experiment). The purpose of this initial design was to design an initial hydrostatic pressure HLT material for an eighth-grade state middle school even semester, which was then tested in the second stage of the teaching experiment to answer first research question in this study. In the teaching experiment, there were two stages: the teaching experiment (cycle 1) and the teaching experiment (cycle 2). Teaching experiment design was used to deliver teaching material and to observe students' conceptual understanding, experimental skills, and problem-solving abilities. After the experimental teaching phase was completed, the researcher conducted a retrospective analysis of what had been obtained in the previous stages of the discussion section.

Activities in Preliminary Design in Understanding Hydrostatic Pressure Using the Inquiry-Based Learning Trajectory

Activity 1. Understand and Construct the Concept of Hydrostatic Pressure

Activity 1 was designed to construct the concept of hydrostatic pressure, train pupils' reasoning, and visualise hydrostatic pressure. The following describes the initial knowledge of pupils in this first activity to understand the concept of hydrostatic pressure and the characteristics of the walls of the dam building. The goal is to understand and construct the concept of hydrostatic pressure using dam-wall drawings. We formulate a hypothesis based on the problem and initial observations. In the initial description of learning, the teacher first conditioned the pupils to sit in the groups. Next, the teacher asked them to perform Activity 1 and look for answers as to why the dam walls were getting lower and thicker (Figure 2). The teacher then conveys the learning objectives and distributes student activity sheets (SAS) 1.

Figure 2

(a) Water dam (b) Bottle filled with water

(a) (b)

The teacher guided the students to observe and answer the problems in SAS 1. The activities in SAS 1 are as follows: (1a) Making a hypothesis, is there a relationship between hydrostatic pressure and the design of a dam wall? To answer this question, students must first answer the following questions: (1b) What factors affect the amount of hydrostatic pressure? What is the value of hydrostatic pressure at each point from the surface to the bottom of the dam? Is it smaller or bigger? (1c), see Figure 3, and describe the results of the observations. Then, (1d) students were asked to formulate hypotheses based on the problems and observations that had been made. When completing SAS 1, students were allowed to discuss with their group members. The teacher guides students in discussing the conjecture of students' thinking in Activity 1, which is presented in the following table.

Table 1

Pupil thoughts in activity 1

Learning activity	Observing the dam wall drawings Make a hypothesis
	Allegations of students' thoughts on the activities carried out
	Pupils visualise what they think the thickness of the dam wall is.
	Why are dam walls getting lower and thicker? They answered this problem in their own way and ability
	Pupils are asked to make a hypothesis, whether there is a relationship between hydrostatic pressure and the design of the dam wall
	What factors affect the amount of hydrostatic pressure?

	What is the value of hydrostatic pressure at each point from the surface to the bottom of the dam? Is it smaller or bigger? Why are dam walls getting lower and thicker? They answered this problem in their own way and ability

Another stage of this activity is reflection. The teacher guides students to formulate hypotheses according to the achievable goals. After students follow the learning process, they can formulate hypotheses related to hydrostatic pressure, namely hydrostatic pressure which depends on the depth of the liquid. The deeper the liquid, the greater the hydrostatic pressure. This was formulated by students from the observations in Figure 2(b), which show different water jet distances. The deeper the hole in the bottle, the greater the water emissions. This indicates that the hydrostatic pressure increased.

Activity 2. Make an Experimental Design from the Available Tools and Materials

Activity 2 was designed to give pupils the opportunity to design experiments using the tools and materials provided. Starting with the lesson, the teacher conditioned the students to sit in. Next, the teacher asks students to carry out Activity 2 and design an experiment that will be carried out with the tools and materials available. Then, the teacher presents the learning objectives and distributes SAS 2. The teacher asks students to write their names on the SAS they have been given, and then asks students to read the SAS given first together and discuss what needs to be done. The teacher guided students in carrying out experimental design activities using the tools and materials available. When completing SAS 2, students were allowed to discuss with their group members. The teacher guided the students in discussions.

Activity 3. Conduct an Experiment Based on the Experimental Design That Has Been Made

At the beginning of the learning process, the teacher first conditioned the students so that they could do experiments. This experiment required cooperation between the students in the groups. There were students holding bottles, students who opened the water faucet and bottle caps, students who measured the spray of water, and students who filled the data in the table. The teacher then asked the students to perform the experiment outside the classroom.

Activity 4. Drawing Graphs

Students created graphs that showed the relationship between the variables measured in the experiment and analysed the experimental results whether they were in accordance with the proposed hypothesis. The students' initial knowledge of this fourth activity is their ability to make and read graphs. Create and read graphs of the experimental results: Starting with the lesson, the teacher first conditioned the students to sit in groups. The teacher then asked the students to draw a graph from the experimental data outside the class.

Activity 5. Solving Some Problems Related to Hydrostatic Pressure

The teacher instructed pupils to analyse the conclusions from the experimental data graphs carried out with the hypotheses that have been made before. Then, students solved several problems related to hydrostatic pressure, including by looking at the experimental results obtained, whether they were in accordance with the hypothesis previously proposed. From the graphs obtained, students can find a relationship with the hypothesis at the beginning of Activity 1. Students found reasons for the unequal thickness of the dam walls. At the bottom of the dam, the dam wall must be thicker so that it does not break. In other words, the dam can withstand water pressure. The teacher found that from the results of the experiments conducted, students easily found answers to the problem of why dam walls have different thicknesses. Students are looking for thicker dam walls down to the bottom of the dam to be able to withstand water pressure.

Experiment Design to observe students' conceptual understanding, experimental skills, and problem-solving abilities.

1. Pilot Experiment (Cycle 1)

Cycle 1 of the research experiment was to try a hydrostatic pressure learning design with HLT 1 on six students of state middle school in Palembang with different abilities, namely, medium high and low. The student names and abilities are MFAR (high), AF (average), AJA (average), and MZA (low). The selection of the six students was based on discussions with a science teacher teaching at school. In cycle 1, the researcher acts as a model teacher; besides that, the researcher also observes and analyses things that happen when a series of activities are carried out. The pilot experiment consisted of five parts.

Activity 1: Understand and Construct the Concept of Hydrostatic Pressure Using Images of Dams and Formulate Hypotheses Based on Problems and Preliminary Observations That Have Been Made

At this meeting, the teacher opened the lesson by asking students about their readiness to learn, then explained the learning objectives, and made perceptions about the context to be taught. The teacher then asked the students to sit with their group mates. Students were given student activity sheets (SAS 1), after which they were asked to discuss completing the SAS 1. Some of the initial questions from the teacher "Is there a relationship between hydrostatic pressure and the design of a dam wall?". “Yes, there is,” said the student. "What factors affect the amount of hydrostatic pressure?" Some students answered "Weight and depth of water". bigger? "Asked the teacher. "The bigger it is, because the liquid that drops will be more and more", answered the student.

Results. of student observations Figure 3, following excerpts of student notes: "The water in the bottle gushes out through 2 holes in the bottle. But the water under the hole will not come out because the depth of the water does not allow water to escape through the two holes." A summary note of the student's observations is that water at a height below the hole will not gush out because the water level does not allow it. The following is the formulation of the hypothesis based on the problems and observations made.

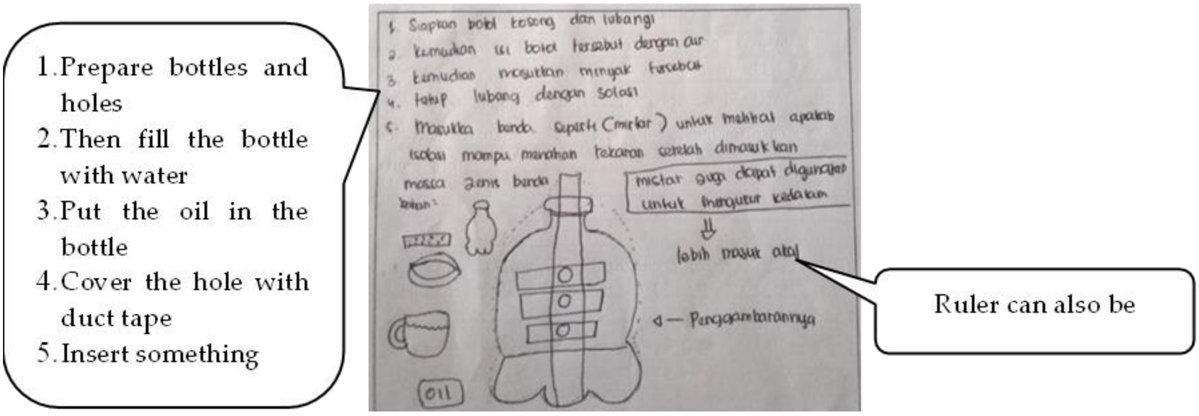
Hypothesis 1: The pressure on the dam is getting higher.
Therefore, an increasing water volume inside the dam wall will become thicker.
Hypothesis 2: Water that is below the level of the hole will not come out.

Activity 2: Make a Trial Design of Available Tools and Materials

Activity 2 aimed to enable students to design experiments to test the hypotheses. In SAS 2, the following tools and materials are provided: water, cooking oil, empty bottle (1000 ml), ruler, and screen. The students were then asked to draw an experimental design with the tools and materials. The following is a picture of students' experimental design.

Figure 3

Image of the experimental design that will be carried out by students

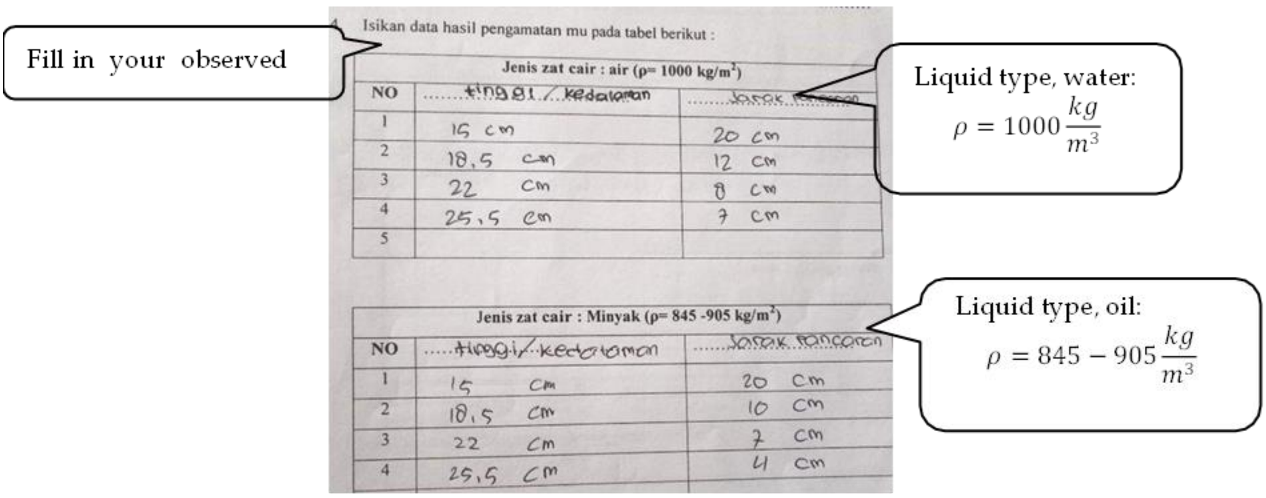


Activity 3: Conduct an Experiment Based on the Experimental Design that Has Been Made, Collect Observation Data, and Fill in the Observation Table

On the student activity sheet (SAS) 3, students were given two tables. The first table for liquid types is water, whereas the second table for liquid types is cooking oil. There are three columns in each table. The first column number and the second and third columns are the observed variables. Variable names are left blank, with the hope that students will write them according to the previous experimental design. From Figure 6, it can be seen that the second column variable is the height or depth of the hole, whereas the third column is the variable distance of the water jet or oil jet distance. The table shows the four different bottle-hole depths. Students find data on the distance of the water spray and the distance of the oil jet through the hole in the bottle that was made. The data are presented in the table shown in the following figure.

Figure 4

Water and oil experiment data obtained by students



Isikan data hasil pengamatan mu pada tabel berikut :

Jenis zat cair : air (ρ= 1000 kg/m^3)

NO	......tinggi / kedalaman	......Jarak ...
1	15 cm	20 cm
2	18,5 cm	12 cm
3	22 cm	8 cm
4	25,5 cm	7 cm
5		

Jenis zat cair : Minyak (ρ= 845 -905 kg/m^3)

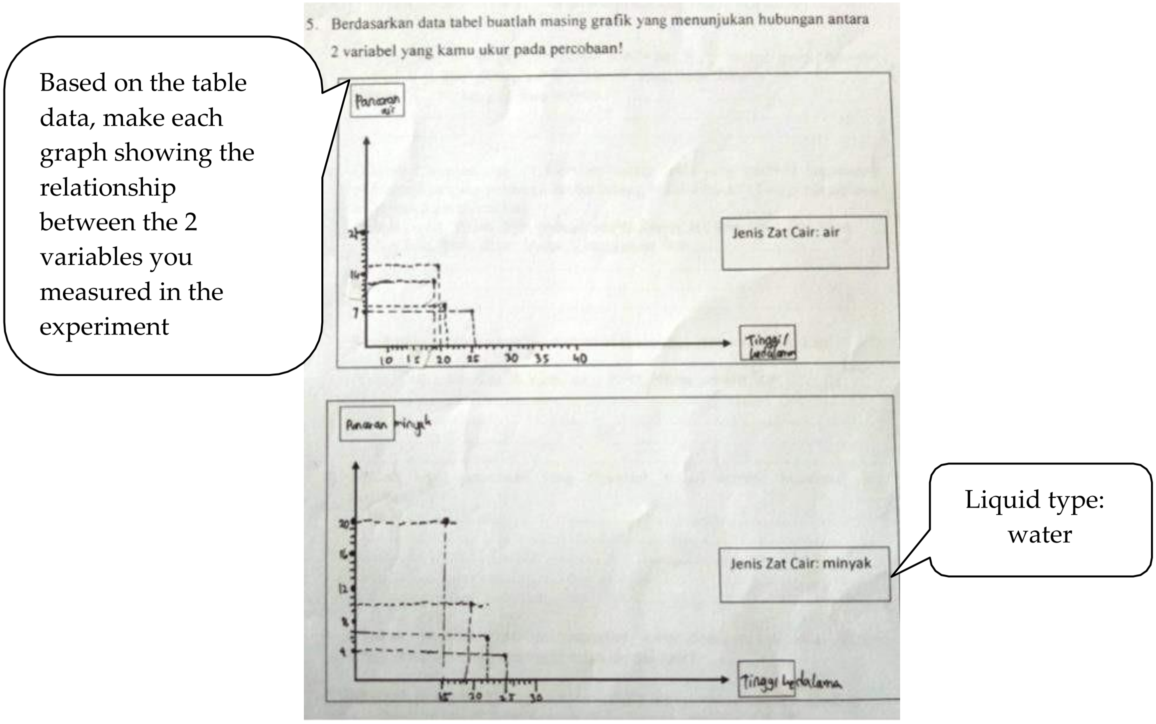
NO	......tinggi / kedalaman	......Jarak pancaran
1	15 cm	20 cm
2	18,5 cm	10 cm
3	22 cm	7 cm
4	25,5 cm	4 cm

Activity 4: Create a Graph Showing the Relationship Between the Variables Measured in the Experiment and Analyze the Experimental Results to Determine whether They Support the Proposed Hypothesis

In Activity 4, students are expected to be able to work on SAS 4, which aims to move the table data into graphs. In SAS 4, there are two diagrams consisting of an x-axis and a y-axis for two different types of fluid data, namely, water and oil. In the diagram, students were expected to write variable names for the x- and y-axes. The following is a graphic image of the students' work.

Figure 4

Graph of the results of experiments with water and oil obtained by students



Activity 5: Solving Several Problems Related to Hydrostatic Pressure, Including Looking at the Experimental Results to See whether They Are in accordance with the Hypothesis Previously Proposed

Activity 5 aims to train students to analyze various problems at the beginning of learning, including connecting experimental results with hypotheses that have been made before. The following are the results of the analysis and students' answers to these questions. "Why is the jet of fluid so different for different orifices". The student answered, "Because each hole can release water with a different pressure." How much does the area of the liquid jet change when the depth changes? The teacher asked. Some students answered "On the surface of the liquid, the pressure is small, and the lower the pressure, the greater the pressure. Therefore, there is a difference in water emissions." "As it is known that oil and water have different densities. What is the difference in the beam distance when the bottle hole is opened? The student answered, "which is farthest from the surface because the pressure is small and closest to the base because the pressure is large." Furthermore, the teacher's question, 'Write conclusions based on the results of the experiment you did!'. Students answered, "In conclusion, the more water you get, the greater the pressure." "Are the experimental results obtained in accordance with the proposed hypothesis?", asked the teacher. Students answer "According."

"Based on the answers to the problems presented at the beginning using the conclusions that have been obtained. Can the experiment you design answer this, and why are dam walls designed to become thicker? Student has answered, "Because the lower you go, the greater the pressure, so to withstand the water pressure, the walls are made thicker."

The purpose of learning Activity 5 is for students to be able to solve several problems related to hydrostatic pressure, including seeing whether the experimental results obtained are in accordance with the hypothesis previously proposed. However, from the students' answers to question 6c, it appears that they cannot see the relationship between density and hydrostatic pressure. Students could only see the relationship between depth and hydrostatic pressure. Interestingly, when connected with equations (1) and (3) above, which were formulated by students, it can be concluded that students were not able to relate the weight of objects to the density of objects.

2. Experimental Learning (Cycle 2)

After repairing the HLT in the experimental pilot, a teaching experiment was conducted (cycle 2). The researcher acted as the model teacher. Cycle 2 was held in eighth grade with 32 students. For the implementation of learning, students were divided into seven groups. The four groups consisted of five students, and the other three groups consisted of four students. The division of fixed groups is based on a combination of high-, medium-, and low-ability groups. At this experimental teaching stage, there were no observers, with the hope that observations would be made by observing the learning videos.

a) Activity 1: Understanding and Constructing the Concept of Hydrostatic Pressure Using Pictures of Dams and Formulating Hypotheses based on the Problems and Initial Observations that Have Been Made

At the first meeting, the teacher opened the lesson by asking the students about their readiness for learning. Next, the teacher conveys the learning objectives and creates perceptions of the context to be used. The teacher then asked the students to sit with their group friends, each consisting of four or five people. Group 1 is DCS, GRT, MAZ, NK, CMEP. Group 2, namely MRF, MFAR, MZ, and RK. Group 3, namely MRM, AK, MRK and AF. Group 4 is FAW, NRF, HPK, and HA. Group 5 is AH, ARF, AJA, AH and MRF. Group 6, namely TMP, NFA, FAT, MAF and MDA. Group 7, namely ANP, GAM, NRP, NR and TNA.

In Activity 1, the activities aimed to train students to formulate the hypotheses of a problem. The formulation of this hypothesis is in accordance with the steps in the inquiry learning model and the scientific approach. What was interesting about the students' answers to the initial questions was that the students had guessed correctly that hydrostatic pressure depended on the liquid, and when asked about factors other than water depth, they mentioned the density of the liquid. Student answers in experimental learning were different from student answers during cycle 1 (piloting). During the trial, according to the students, another factor besides depth is the weight of the liquid (i.e., the product of mass and gravity). If formulated mathematically, the student's answer can be formulated as.

$$P_h \propto \rho.h \text{..} (1)$$

This shows that hydrostatic pressure is proportional to the density and depth of the liquid. This formulation is better than the formula in Cycle 1 (piloting).

b) Activity 2: Create an Experimental Design using Available Tools and Materials

Activity 2 has the goal of allowing students to design experiments to test the hypotheses that have been made. In SAS 2, the following tools and materials are provided: water, cooking oil, an empty bottle (1000 ml), a ruler, and tape. The students were then asked to draw an experimental design with the tools and materials. The following is a picture of the students' experimental design. Students wrote that the distance between the bottle holes was the same. However, there are no instructions on how to measure the depth of the bottle hole, whether measured from the bottom or surface of the water. In addition, there are no instructions on how to punch holes into bottles. Could the big watering hole be any different? Not explained. In addition, the observation table form was not required. Cooking oil was not used during the experimental stage. Experimental steps: 1) Prepare tools and media materials; 2) Drill the bottle first with four holes; 3) Ensure that the distance between the holes is sparse; 4) Cover the holes withDuct tape; 5) Put water in the bottle; 6) Open the bottle holes one by one; and 7) Measure the distance of the water jet using a ruler.

c) Activity 3 Conducted an Experiment Based on Experimental Design, Collected Observational Data, and Filled It into the Observation Table

Students were given two tables on a Student Activity Sheet (SAS) 3. The first table for liquid types is water, whereas the second table for liquid types is cooking oil. There are three columns in each table. The first, second, and third columns are the observed variables. Variable names are left blank, with the hope that students will write them according to the previous experimental design. Students find data on the distance of the water spray and the distance of the oil jet through the hole in the bottle that was made. However, the students did not conduct any experiments using cooking oil.

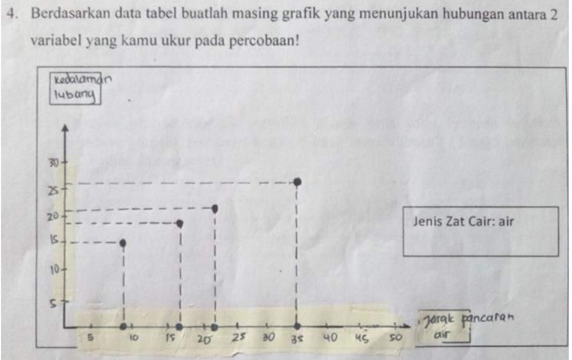
In Activity 3, students were expected to find ways to measure and collect data correctly. Students were expected to work conscientiously and carefully. In addition, students are expected to work well with all group members. Students must understand the variables to be measured and observed. Students must understand how to measure them to avoid errors from occurring. If students do not understand or are still unsure, they should ask the teacher how to measure it. As shown in Figure 4.10, there was a student error in measuring the depth of the bottle hole. The deepest hole was located at the farthest distance. In fact, in the data obtained by students, the farthest beam distance is at the shortest hole, or the shortest beam distance is at the farthest hole. This is against the truth. This is because students measured the depth of the bottle hole from the bottom of the water, not from the surface of the water.

d) Activity 4: Make a Graph Showing the Relationship Between the Variables Measured in the Experiment and Analyze the Experimental Results, whether They Are in accordance with the Proposed Hypothesis

In Activity 4, students are expected to be able to work on SAS 4, which aims to move the table data into graphs. In SAS 4, there are two diagrams consisting of an x-axis and a y-axis for two different types of fluid data, namely, water and oil. In the diagram, students were expected to write variable names for the x- and y-axes. The following is a graphic image of the students' work.

Figure 5

Experimental graph obtained by students



The purpose of learning in Activity 4 was for students to be able to make and read graphs from the results of the experiments. In Figure 6, it appears that students determined the variable depth of the hole on the y-axis and the variable distance of the liquid jet on the x-axis. Students seemed to be trying to make a fixed scale on the x- and y-axes. Students seemed to understand how to read graphs. The students read the chart as follows: the deeper the hole in the bottle filled with liquid, the farther the water jets. This is in accordance with the experimental observations.

e) Activity 5: Resolving Several Problems Related to Hydrostatic Pressure, Including Looking at the Experimental Results and whether They Are in accordance with the Hypothesis Previously Proposed

Activity 5 aims for students to analyse problems at the beginning of learning, including connecting experimental results with the hypotheses made. The following are the results of the analysis and students' answers to these questions. "Why are the jets of fluid so different for different orifices?". The student answered, "Because of the difference in the depth of each hole." "How much does the level of fluid jets change as the depth changes?". The student answered, "If the depth of the water increases, the length of the jet also increases." The teacher asked,' As you know, oil and water have different densities. What is the difference in the beam distance when the bottle hole is opened? Write a conclusion based on the results of the experiment you did!". Students answered, "The deeper the water, the farther the water and the greater the hydrostatic pressure." "Are the experimental results obtained in accordance with the proposed hypothesis?". Students answered, "Yes, appropriate". The teacher asked again, "Explain the answers to the problems presented at the beginning using the conclusions that were obtained. Can the experiment you design answer this, and why are dam walls designed to become thicker? "Yes, because the deeper the hydrostatic pressure, the greater," said the student.

Figure 5a

Answered students' numbers 6 to 8

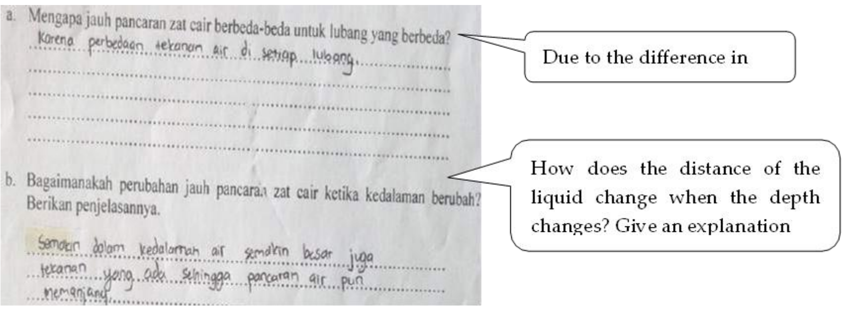
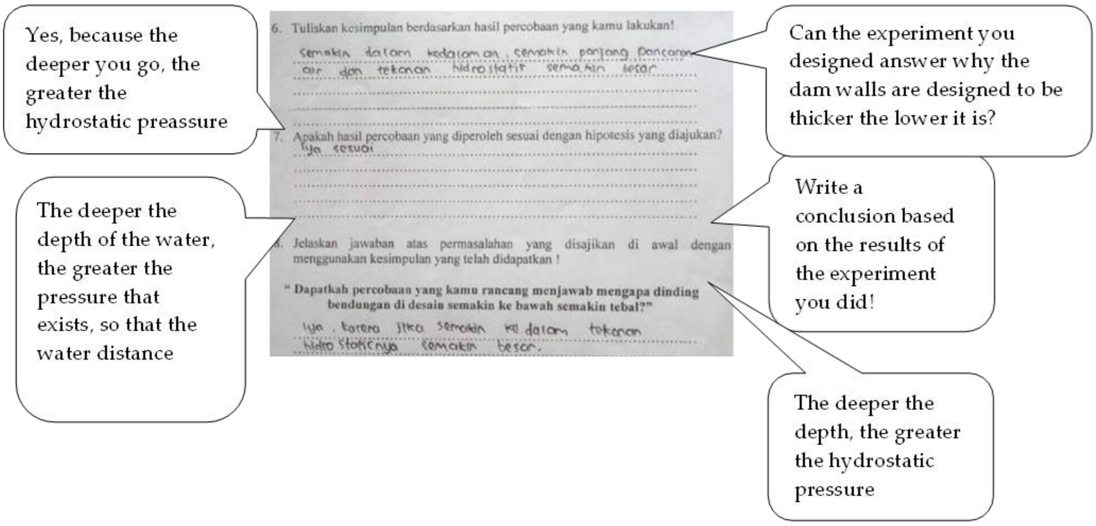


Figure 5b

Answered students' numbers 6 to 8



Discussion

Based on the results of the research and retrospective analysis that have been done, the problem formulation in this study will be answered. The primary focus of this research is to investigate the learning trajectory of middle school students in Palembang using the Hypothetical Learning Trajectory (HLT) framework. The learning trajectory is designed to explore contextual factors that support students' conceptual understanding and engagement with hydrostatic pressure concepts. The causes of student learning difficulties can come from the students themselves or from outside the students, for example the way the subject matter is presented, or the learning atmosphere is carried out (Kempa, R.F., 1991).

At the initial design stage, researchers designed student learning trajectories to understand hydrostatic pressure materials through five activities. The five activities are : (1) understanding and constructing the concept of hydrostatic pressure using pictures of dams, and formulating hypotheses based on the problems and initial observations that have been made; (2) making a trial design of available tools and materials; (3) conducting experiments based on the experimental design that has been made, then collecting observational data and filling it into the observation table; (4) making a graph showing the relationship between the variables measured in the experiment and analyzing and concluding the results of the experiment; and (5) solving several problems related to hydrostatic pressure, among others, to see whether the experimental results are in accordance with the previously proposed hypothesis. In this stage, we try to train and observe student conceptual understanding.

In the experimental pilot stage, students will be engaged to the learning process and to develop their skills such as making hypothesis, understanding the graph and data, seeking information and conducting investigation. the students experienced errors in measuring the depth of bottle holes. In addition, students experience difficulties reading and understanding graphs. Most students' answers were in accordance with the expectations of the researchers. Another difficulty experienced by the students was reading and understanding the graphs in SAS 4. However, students could describe these graphs. The difficulty is observed when the experimental data depicted in the graph differ from the facts. Supposedly, if students can understand the graph well, they can realize that there has been an error in measuring the depth of the bottle hole (Berhanu and Sheferaw 2020). At the teaching experiment stage, the learning process was carried out after the researcher revised the HLT that had been carried out in the experimental pilot. Learning during the teaching experiment went well according to the HLT that had been designed. It is just that when working on SAS 3, it takes quite a long time, namely, conducting experiments based on experimental designs made to collect data. This was because the experiment had to be conducted outside the classroom. In addition, there are students who are willing to get their pants wet as long as experimental data can be obtained. Because it was done outside the class by all groups, the situation became rowdy and a little disturbing to the other classes who were studying.

In this study, hydrostatic pressure learning was conducted using inquiry learning models and scientific approaches. An investigation refers to conducting a research. Inquiry strategy refers to a series of learning activities that maximally involve all students' abilities to seek and investigate systematically, critically, logically, and analytically, so that they can formulate their own findings with confidence (Kim et al., 2021).

The inquiry learning model used in this study requires students to be more active in asking questions, seeking information, and conducting investigations to find out for themselves a concept in which the teacher guides students in carrying out activities by giving initial questions and directing them to a discussion activity. Inquiry provides students with a real and active learning experience. Students learn to become scientists where they are given the opportunity to investigate and find their own answers (Wenning, C.J., 2011). Students were also can be supported using feedback from teachers during the learning process (Ole & Gallos, 2023).

However, it seems that it is still difficult for eighth-grade students of state middle school to apply this model purely and purely. The teacher's help is still needed to correct student misconceptions, such as an incorrect understanding of how to measure the depth of the bottle hole in this learning activity. After implementing the HLT designed with the inquiry learning model and scientific approach, it can be concluded that this research can produce a learning trajectory that can help students understand the concept of hydrostatic pressure from the informal to the formal stage.

Each activity within the design research framework is strategically structured to foster students' skill development. To evaluate this progression, we have elaborated on the assessment methods employed throughout the study. These assessments include Student Activity Sheets (SAS), which systematically document students' ability to formulate hypotheses, design experiments, and analyze data; observational field notes, which capture students' engagement, problem-solving strategies, and collaborative discussions; and graph interpretation tasks, which assess their ability to derive meaningful insights from experimental results. Furthermore, we have emphasized the observed progression in students' skills from the pilot experiment (Cycle 1) to the teaching experiment (Cycle 2), highlighting notable improvements in their reasoning abilities, capacity to analyze relationships between variables, and overall scientific inquiry competencies.

Conclusion and Implications

In this study, a learning trajectory was produced that can help students understand the concept of hydrostatic pressure, whose magnitude depends on the depth of the liquid, mass of the liquid, and gravity field. The learning trajectory can support the students' understanding of the concepts in the five activities. First, students looked at a dam drawing in SAS 1 and hypothesized that the dam wall was designed to increase the thickness of deeper walls. Second, the students created an experimental design based on the tools and materials in SAS 2. Third, students conducted an experiment based on the design that has been made. Fourth, the students described a graph of the experimental data. Then, students analyze the graph to find answers, and determine whether the hypothesis that has been made is proven true. Finally, students answered several questions to build their understanding of hydrostatic pressure and related the experimental findings to the problem formulation in SAS 1, namely: why is the dam wall designed to be deeper and thicker? Furthermore, the results can be used to implement inquiry-based activities using a broader-designed learning trajectory. This can also be used as a reference for further research in different learning contexts.

This research is expected to be useful (1) for students to train to develop natural knowledge, improve reasoning abilities, and express ideas in studying liquid pressure material through simple experiments; (2) for teachers, it can be used as an example and information in the learning process can especially help teachers in presenting learning for liquid pressure material using an inquiry-based learning model; (3) for other researchers, it can be used as reference material for further research or studies on other science learning topics using an inquiry-based learning model.

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Appendix

Appendix 1a
Sample of Lesson Plan

Lesson Plan 1 – Hydrostatic Preassure

A. *Identity*

Educational Institution	SMP Negeri 9 Palembang
Subject	Integrated Science
Class/Semester	VIII / II
Main Material	Pressure in Matter
Time Allocation	5 Lesson Hours (1st Meeting: 3 Hours, 2nd Meeting: 2 Hours)
Note	This lesson plan is specifically for the 2nd meeting.
Educational Institution	SMP Negeri 9 Palembang
Subject	Integrated Science
Class/Semester	VIII / II

B. *Core Competencies (KI)*

1. KI.3: Understand and apply knowledge (factual, conceptual, and procedural) based on curiosity about science, technology, art, and culture related to observable phenomena and events.
2. KI.4: Process, present, and reason in concrete domains (using, analyzing, assembling, modifying, and creating) and abstract domains (writing, reading, calculating, drawing, and composing) according to what is learned at school and other sources from similar perspectives/theories.

C. *Basic Competencies and Indicators of Competency Achievement (IPK)*

Basic Competencies	Indicators of Competency Achievement (IPK)	Description
3.8 Explain the pressure of matter and its applications in daily life, including blood pressure, osmosis, and capillarity in plant transport tissues.	3.8.1 Explain the concept of pressure. 3.8.2 Compare the relationship between force and surface area in relation to pressure.	Understanding pressure concepts and their applications.
4.8 Present experimental data to investigate the pressure of liquids at certain depths, buoyant force, and capillarity, for example, in plant stems.	4.8.1 Present experimental data on liquid pressure at certain depths. 4.8.2 Present experimental data on the application of pressure principles in the capillarity process for substance transport in plants.	Conducting and presenting experiments related to pressure.

D. *Learning Objectives*

After studying Hydrostatic Pressure, students are expected to:

1. Predict (hypothesize) the factors affecting hydrostatic pressure experienced by objects.
2. Analyze the effect of depth on hydrostatic pressure.
3. Analyze the effect of density on hydrostatic pressure.
4. Present experimental results of hydrostatic pressure.
5. Conclude the concept of hydrostatic pressure.
6. Apply the concept of hydrostatic pressure in daily life.

E. *Learning Materials*
Pressure in matter (especially liquid):

F. *Learning Methods*
a) Approach: Scientific
b) Learning Model: Inquiry
c) Learning Methods: Practicum, Discussion, Q&A.

G. *Learning Media*
1. Media: LCD projector, screen, laptop, PPT media, school environment.
2. Tools and Materials: Spring balance, beakers, weights, water, cooking oil, mineral bottles, tape, and Hydrostatic KIT.

H. *Learning Resources*
1. Ministry of Education and Culture. 2017. Science for Junior High School/MTs Class VIII Semester 2. Jakarta: Ministry of Education and Culture (pp. 1-33).
2. Ministry of Education and Culture. 2017. Teacher's Book _Science for Class VIII_. Jakarta: Ministry of Education and Culture (pp. 320-318).
3. Tim Abdi Guru. Integrated Science for SMP/MTs Class VIII. Jakarta: Erlangga (pp. 228-243).
4. School environment.

İ. *Learning Step*

Learning Steps	Inquiry Model Syntax	Activity Description	Time Allocation
Introduction	-	• The teacher prepares the students for learning. • The teacher establishes a pleasant learning environment. • The teacher engages in an apperception exercise and motivates the students by asking: – Have you ever gone diving? What sensations did you experience in your ears while diving? – Did you feel that your ears were under pressure? – As you dived deeper, did you experience greater pressure? – Why might this phenomenon occur?	5′
Core Activities	Orientation Stage	• The teacher communicates the learning objectives and their relevance in everyday life. • The teacher outlines the scope of the material and the activities to be undertaken. • The teacher details the learning activities that will be conducted.	70′

		• The teacher directs the students' attention by providing a stimulus through the presentation of the following image. 	
	Formulating the Problem	• The teacher gives the students the opportunity to formulate as many questions as possible that have been identified through observation, for example: 1. What is the relationship between the pressure of a liquid, the density of the substance, the height of an object, and the Earth's gravitational force? 2. How can the pressure in a liquid be determined?	
	Formulating the Hypothesis	• The teacher divides the students into several groups consisting of 4–6 students. • The teacher distributes the worksheet to each group. • The teacher guides the students in reading and scrutinizing the worksheet. • The teacher guides the students in carrying out the activity as outlined in the worksheet, namely: **"Conduct an experiment on the pressure of a liquid at a specific depth."**	
	Collecting Data	• The students discuss the results of the experiment. • The teacher asks the students to engage in group discussions to answer the questions in the worksheet, supervising and guiding them throughout the discussion.	
	Testing the Hypothesis	• Students verify whether the formulated hypothesis is correct by comparing it to the conducted experiment and other learning resources.	
	Formulating the Conclusion	• The students draw conclusions from the experiment, for example: The pressure of a liquid is influenced by the density of the liquid and the depth of the object. $Ph = \rho.g.h$ The students communicate the results of their group work.	
Closing		• The teacher clarifies and communicates the correct	5′

	answers from the discussion: a) The pressure exerted by a stationary liquid is called hydrostatic pressure. The pressure of a liquid is influenced by its density and the depth of the object. Ph = ρ.g.h b) This hydrostatic pressure is important for designing various structures, such as dams for hydroelectric power plants and submarines. • The teacher, together with the students, reflects on the learning process that has taken place. • The teacher concludes the lesson while offering a closing salutation.

Appendix 1b

Sample of Student Activity Sheets (SAS)

Student Activity Sheets (SAS) - Hydrostatic Pressure

Learning Objective: Investigate hydrostatic pressure

What do you need?

The following materials are required for the experiments:

For Experiment 1:

1. Two beakers
2. U-shaped pipe and U-shaped hose
3. Funnel
4. Colored water
5. Coconut oil or cooking oil
6. Balloon to cover the funnel

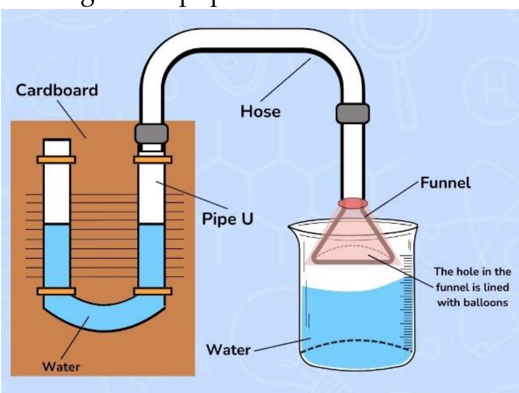
For Experiment 2:

1. Mineral water bottle
2. Cutter or hole punch for the bottle
3. Colored water
4. Coconut oil or cooking oil
5. Tape to cover the holes in the mineral water bottle.

What Should You Do?

Experiment 1

1. Arrange the equipment as shown in the following image.



2. Fill the beaker with water.
3. Insert the funnel into the beaker and vary the depth of the funnel.
4. Observe the difference in water levels in the U-shaped pipe.
5. Repeat the experiment by replacing the water with cooking oil.
6. Record your observations in the table below.

Table 1. Experimental Data of Liquid Pressure in a U-Shaped Pipe

No	Depth (h) (cm)	Difference in Height (Δh) (cm)	
		Water	Coconut Oil
1			
2			
3			
4			
5			

Experiment 2

1. Arrange the equipment as shown in the following image.


2. Make holes in the mineral water bottle at several points with different heights.
3. Seal all the holes in the bottle using tape.
4. Fill the mineral water bottle with water.
5. Remove the tape from the holes.
6. Observe the difference in the water spray distance from each hole in the mineral water bottle.
7. Repeat the experiment by replacing the water with cooking oil.
8. Record your observations in the table below.

Tabel 2. Table 2. Experimental Data of Liquid Pressure in a Mineral Water Bottle

No	Hole Depth in the Bottle (h) (cm)	Spray Distance (cm)	
		Water	Coconut Oil
1			
2			

3			
4			
5			

What Should You Discuss?

1. In your opinion, which is greater: the density of water or the density of cooking oil?
2. How does the difference in water height in the U-shaped pipe change when the funnel is inserted deeper into the beaker?
3. Compare the difference in water height in the U-shaped pipe at each funnel depth when inserted into the beaker filled with water and when filled with cooking oil.
4. How does the spray distance of water and cooking oil from the holes in the mineral water bottle compare?
5. Compare the spray distance of water and cooking oil from the mineral water bottle when the hole covers are removed.
6. The difference in height and spray distance is caused by the pressure of the liquid (water and oil) transmitted through the funnel and hose in Experiment 1 or through the holes in the mineral water bottle in Experiment 2. What factors affect the magnitude of pressure in this experiment?

What Should You Conclude?

Based on the experiments and discussions you conducted, what can you conclude?

1. The density of water … the density of cooking oil (fill in with the symbol >, =, or <).
2. Calculate the difference for each experiment!
3. Compare the water height in the U-shaped pipe and the water level in the beaker.
4. Mention the factors that influence the results.