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Designing a STEM-Based Learning Trajectory for Understanding Median through Coffee pH Measurement Activities

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Abstract

This study addressed students' difficulties in understanding the median as a conceptual measure of central tendency rather than a procedural computation. It aimed to design and validate a STEM-based learning trajectory to support students' understanding of the median through coffee pH measurement activities. The study employed a design research methodology of the validation study type, consisting of a preliminary design, pilot experiment, teaching experiment, and retrospective analysis. The subjects were tenth-grade vocational high school students in Palembang majoring in culinary arts. Data were collected through classroom observations, student worksheets, semi-structured interviews, and video recordings. The results showed that the STEM-based learning trajectory enabled students to progress from concrete data collection to data organization, identification of the middle position, formal median calculation, and contextual interpretation. The instructional design can support students' conceptual understanding. A STEM-based learning trajectory using the context of coffee pH measurement can serve as an alternative instructional strategy to help students gradually develop a conceptual understanding of the median while simultaneously enhancing statistical literacy through authentic experiences of collecting, processing, and interpreting data.

Keywords: Coffee; learning trajectory; median; pH measurement; STEM

INTRODUCTION

The rapid growth of data-driven information in the digital era requires students not only to perform mathematical calculations but also to use mathematics to understand, interpret, and solve problems in various real-life contexts (Yusuf et al., 2017). The improvement of mathematics education quality increasingly demands instructional approaches that connect statistical concepts with real-world phenomena, so that students not only understand theoretical ideas but are also able to apply them in authentic contexts. Statistics education equips students with logical reasoning skills, the ability to collect and analyze data systematically, and the capacity to make evidence-based decisions that are valuable both in academic settings and in everyday life (Zainudin, 2024; Utomo, 2021). One important concept in statistics, particularly in measures of central tendency, is the median, which is used to represent the middle value of a data set, especially when the data are not symmetrically distributed or contain extreme values (Cazorla et al., 2023). A conceptual understanding of the median enables students to develop reasoning skills, model real-life situations, and explain the results of data analysis mathematically. Research in statistics education has shown that students often experience difficulties in correctly identifying and interpreting measures of central tendency, as many tend to focus on formulas rather than on conceptual reasoning (Saidi & Siew, 2018). As a result, students often face difficulties when they need to use the concept of the median to solve contextual problems or interpret data in real-life situations. This condition indicates a gap between the way statistics is taught in the classroom and the intended learning objectives.

One instructional strategy that bridges abstract concepts with real-life experiences is the STEM (Science, Technology, Engineering, and Mathematics) approach. Integrated STEM has been globally recognized as a learning approach that can enhance critical thinking, problem-solving skills, and the ability to apply concepts in real-world contexts across various disciplines, including statistics and mathematics (Ilyas et al., 2022). STEM education emphasizes interdisciplinary learning and real-world problem solving, thereby supporting student engagement and cognitive development across multiple disciplines (Akiha et al., 2018). Systematic reviews have identified that design-based and context-based learning models can meaningfully connect disciplinary knowledge with authentic experiences, thereby enhancing student engagement and conceptual understanding (Susanti et al., 2025).

In recent years, research in the field of STEM education has grown rapidly. A systematic study by Li et al. (2020) showed a sharp increase in international publications on STEM education, highlighting various instructional design models that integrate science, technology, engineering, and mathematics to develop students' higher-order thinking skills. Retta et al. (2025) developed a context-based learning trajectory using water pH to support students' understanding of measures of central tendency, including the median, demonstrating that the use of a water pH context can effectively facilitate the learning of statistical concepts through an HLT approach in mathematics instruction. Other studies have shown that STEM learning based on projects (Wati & Ramadianti, 2025), technology integration including the use of learning management systems (Mariani et al., 2025)**,** conincon learning (Reksadini et al., 2022)**,** Artificial Intelligence (Efriani & Arifin, 2025), and concrete activities using contextual settings (Albab et al., 2025; Arivina & Jailani, 2020; Efriani, 2024; Nursyahidah et al., 2023) can strengthen students' mathematical, logical, creative, and systematic thinking skills. As a result, students not only understand concepts procedurally but are also able to connect them to real-life situations and develop reasoning, argumentation, and problem-solving abilities (Nusantara, Zulkardi et al., 2025).

Several studies have shown that design-based research methods, such as the development of learning trajectories, have been successfully used to create context-rich learning sequences that anticipate students' thinking processes and refine instructional actions based on empirical classroom evidence (Guntur et al., 2023). Studies focusing on the development of learning trajectories and the use of realistic contexts have also been widely conducted. These include, among others, the development of a learning trajectory for numeracy using the *New Pempek Matematika* context (Putri et al., 2025), a learning trajectory on the topic of scale using the context of rice field measurement supported by Google Earth (Sari et al., 2025a), learning trajectories based on South Sumatra local wisdom (Utari et al., 2024), the use of the Tourist Destination Bukit Sulap Jambi context (Adha & Putri, 2024), and the integration of the Indonesian shadow puppets and Mahabharata stories in set learning (Risdiyanti & Prahmana, 2021). Empirical findings suggest that the use of realistic contexts has a positive impact on students' conceptual understanding, mathematical literacy, and problem-solving abilities (Fitriyana et al., 2023; Mufti et al., 2023). By positioning realistic contexts as the starting point for learning, a key characteristic of the PMRI approach, it supports students in actively constructing mathematical understanding, moving step by step from concrete real-world situations toward abstract mathematical concepts (Zulkardi & Putri, 2019).

In this study, the integration of PMRI and STEM is realized through the design of a learning trajectory that uses the context of coffee pH measurement as the starting point for statistical learning. The PMRI approach is reflected in the use of an authentic real-world context that encourages students to model and interpret data based on their experiences. Meanwhile, the STEM component is implemented through investigative activities involving measurement using pH indicators, simple experimental procedures, data collection, and data analysis. Through this integration, students engage not only in mathematical reasoning but also in scientific inquiry and technological practices.

Although numerous studies on STEM learning trajectories in statistics have been conducted, most of them employ general contexts such as water pH or internally designed mathematical media, while popular cultural contexts such as coffee have not been utilized as the primary context. The connection between students' everyday cultural experiences (e.g., coffee) and their understanding of statistical concepts, particularly the median, remains limited in the current literature. Therefore, this study offers a novel contribution by integrating a popular cultural context with a structured STEM-based learning trajectory.

The research problem addressed in this study is how an effective STEM learning trajectory can facilitate students' understanding of the median through coffee pH measurement activities, while simultaneously integrating elements of science (pH as a scientific concept), mathematics (median as a statistical measure), technology (pH measuring instruments), and problem solving. Specifically, there is a need to understand the stages of students' thinking through a systematically designed Learning Trajectory based on the context of coffee pH measurement. Accordingly, the purpose of this study is to develop a STEM-based learning trajectory for the topic of median using coffee pH measurement activities. This study is expected to provide insights into how students transition from concrete experiences toward a conceptual understanding of the median.

METHOD

Research Design

This study employed design research methodology, specifically the validation study type, with the aim of developing and validating a learning trajectory for teaching the concept of median through coffee pH measurement activities. Design research was selected because it enables the systematic design, implementation, and refinement of instructional interventions through iterative cycles of analysis, design, classroom experimentation, and retrospective evaluation. This approach allows for close collaboration between researchers and teachers, ensuring that the instructional design aligns with students' needs, classroom realities, and contextual characteristics (Akker & Gravemeijer, 2010; Gravemeijer & Cobb, 2006).

The study was oriented toward the development of a learning trajectory that articulates how students can progressively construct a meaningful understanding of the median concept. The trajectory integrates STEM components by embedding scientific investigation (pH measurement), technological tools (pH meter usage), data organization processes, and mathematical reasoning within an authentic context. Coffee pH measurement was employed as a contextual anchor to facilitate students' transition from concrete experimental experiences to formal statistical understanding. Through iterative refinement and classroom validation, the study sought to produce a theoretically grounded and empirically tested instructional trajectory for median learning. The STEM components integrated in this study are illustrated in Figure 1.

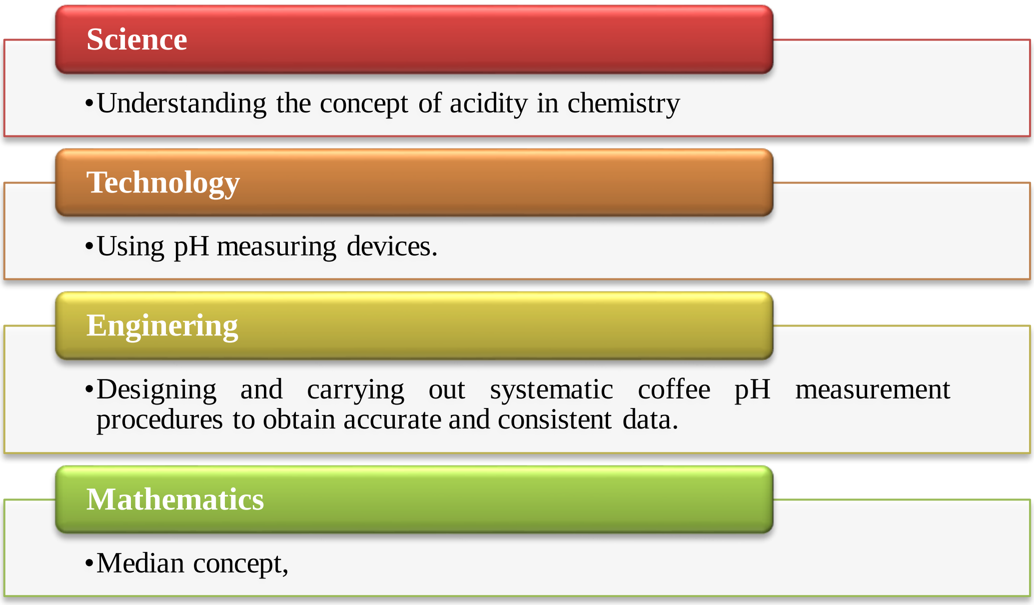


Figure 1. STEM Component in This Research

Participants and Research Setting

This study was conducted at a vocational high school (SMK) in Palembang, South Sumatra, Indonesia. The research took place from November to December 2025 and involved tenth-grade students majoring in Culinary Arts.

The pilot experiment was carried out with a small group of students from Class X.1 to explore the initial feasibility of the instructional design and to refine the Hypothetical Learning Trajectory (HLT). Ten students were selected through purposive sampling based on their mathematical achievement levels, as recommended by the classroom teacher. The participants consisted of three high-achieving students, three low-achieving students, and four students with average achievement. The larger proportion of average-achieving students reflected the general academic profile of the class. Following the pilot phase, the revised learning trajectory was implemented in the teaching experiment involving all students from Class X.2 (n = 25). The class selected for the implementation stage was determined through random sampling from classes that had not participated in the one-to-one and pilot phases, to avoid bias and to examine the applicability of the revised learning trajectory with a different group of students. This phase aimed to examine the practicality and effectiveness of the designed STEM-based learning trajectory in a regular classroom setting.

Consistent with the design research methodology, the study was conducted in three main phases: (1) preparing for experiment, (2) design experiment through pilot and teaching experiments, and (3) retrospective analysis (Akker & Gravemeijer, 2010; Sari et al., 2025b).

Preparing for the Experiment

The preliminary phase began with an extensive literature review covering key aspects relevant to the study, including the concept of median, mathematical literacy, STEM-based learning, and learning trajectory development. In addition, an analysis of the current curriculum was conducted to ensure alignment between the designed instruction and the expected learning objectives. This review aimed to identify the conceptual characteristics of the median and to explore the potential of integrating coffee pH measurement activities as a meaningful and authentic learning context.

Based on the literature review and needs analysis, an HLT was developed to describe the expected progression of students' understanding of the median. The HLT consisted of a sequence of instructional activities designed to support conceptual development, beginning with the introduction of the coffee pH measurement context, followed by data collection and organization, and culminating in determining and interpreting the median within the given context. In addition to the HLT, several instructional materials were developed to support classroom implementation, including student worksheets, a learning module, and a teacher guide. These materials were designed to facilitate the integration of STEM components and to support students' engagement in data-driven learning activities.

To ensure content validity and instructional feasibility, all learning materials were reviewed and validated by mathematics education experts and experienced teachers. The validation process focused on the accuracy of content, clarity of instructions, appropriateness of the context, and the practicality of implementation in classroom settings.

Design Experiment

The design experiment consisted of two phases: a pilot experiment and a teaching experiment. In the pilot experiment, the initial HLT and the developed instructional materials were implemented with a small group of ten students. The purpose of this phase was to examine the readability of the student worksheets, the clarity of instructions for the coffee pH measurement activities, and the alignment between the planned learning sequence and students' actual ways of thinking. In addition, this phase aimed to identify potential learning difficulties and practical issues that might arise during implementation. The findings from the pilot experiment served as the basis for revising and refining the HLT as well as the instructional materials before they were used in the subsequent phase.

In the teaching experiment, the revised HLT was implemented with 25 students in a regular classroom setting. During the implementation, multiple data sources were collected to capture students' learning processes. These included classroom observations, student interviews, documentation of students' written work on the worksheets, and video recordings of the lessons. Classroom observations were conducted to examine student engagement, group interactions, and students' responses to the learning activities. Semi-structured interviews were carried out to explore the reasoning behind students' answers, the strategies they employed, and the difficulties they encountered in developing their understanding of the median.

Retrospective Analysis

The retrospective analysis phase involved a comprehensive examination of all data collected during the design experiment. The analysis focused on comparing the HLT with the Actual Learning Trajectory (ALT) that emerged during classroom implementation. This comparison aimed to identify the extent to which the designed learning trajectory aligned with students' actual learning processes, as well as to reveal students' reasoning strategies, learning patterns, and difficulties encountered throughout the activities.

Data from classroom observations, student work, interviews, and video recordings were analyzed qualitatively to trace students' conceptual development in understanding the median. Attention was given to critical learning moments, unexpected student responses, and points where the instructional design either supported or failed to support students' learning progression.

The findings from the retrospective analysis were used to refine and improve the median learning, leading to the formulation of a Learning Trajectory. This LT provides a more accurate and context-sensitive description of how students develop an understanding of the median through coffee pH measurement activities. The LT is expected to serve as a reference for designing mathematics instruction that supports students' understanding concept and mathematical literacy through meaningful STEM-based contextual integration

RESULTS

The preliminary design phase produced an initial HLT grounded in literature review, curriculum analysis, and contextual considerations, which served as the basis for the subsequent pilot and teaching experiments. The HLT is described in Table 1.

Table 1. *HLT of Understanding Median through Coffee pH Measurement*

Activities	Aims	Prediction of Students' Thinking
Activity 1. Exploring the Context: Coffee pH	Students understand that pH values represent coffee acidity and recognize	• Students record different pH values for each sample.

Activities	Aims	Prediction of Students' Thinking
Measurement (situasional)	that real-world phenomena can produce numerical data.	• Some students focus only on identifying the most acidic coffee. • Some students may misunderstand the pH scale (e.g., thinking higher pH means more acidic).
Activity 2. Organizing the Data (model of)	Students can organize numerical data systematically by ordering values from smallest to largest.	• Most students correctly order the data. • Some students may make errors in ordering. • Some students may not understand the purpose of ordering the data.
Activity 3. Identifying the Middle Value Informally (model for)	Students informally recognize the concept of middle value in a dataset.	• Students correctly identify the middle value when the number of data points is odd. • Some student's express confusion.
Activity 4. Formalizing the Median Concept (formal)	Students understand and apply the formal definition and procedure for finding the median for both odd and even datasets.	• Students correctly compute the median after ordering. • Some students confuse median with mean. • Some forget to order the data first.
Activity 5. Interpreting the Median in Context (STEM Integration)	Students interpret the median as a representative value and explain its meaning in the context of coffee acidity.	• Students state that the median represents the typical acidity level. • Some students provide numerical answers without contextual interpretation.

The pilot experiment was conducted to examine the feasibility and clarity of the initial HLT and instructional materials. Overall, the implementation showed that the coffee pH measurement activity effectively engaged students and stimulated active participation during the STEM-based investigation phase. Students demonstrated strong interest in using the pH meter and were able to record measurement data accurately.

During the data organization phase, most students successfully arranged the pH values in ascending order. However, several students required additional guidance to understand why ordering the data was necessary before determining the median. This indicates that the procedural step of organizing data needs clearer conceptual emphasis in the instructional design. Based on these findings, minor revisions were made to the HLT and learning materials, including clearer instructions, additional guiding questions, and enhanced explanations distinguishing median from mean. These refinements were implemented before proceeding to the teaching experiment phase.

The teaching experiment aimed to investigate how the revised HLT functioned in a full classroom setting and to examine the ALT that emerged during the learning process. The findings indicate that the implemented STEM-based activities successfully supported students' conceptual development of the median through a sequence of experiential, procedural, and interpretative learning stages.

Activity 1: Exploring the Context: Coffee pH Measurement

During the activity one, students measured the pH levels of different coffee samples using a pH meter and recorded the results in their worksheets. Classroom observations showed high engagement, active group discussions, and careful data recording. Students compared their findings across groups and began recognizing variations in acidity levels.

This stage successfully positioned students within a meaningful data-generating experience rather than presenting them with abstract numerical datasets. The concrete measurement activity functioned as an entry point to statistical reasoning (Nusantara, Ibarra et al., 2025). Figure 2 shows the pH measurement data for 15 types of coffee typical of Pagaralam.

Task: Record the pH measurement results of each coffee sample in the following table:

No	Jenis Sampel Kopi	Nilai pH
1	Robusta Petik Merah (dark)	5,2
2	Robusta Petik merah (medium).	5,5
3	Robusta Petik merah (Light)	5,3
4	Robusta Petik merah asal	5,1
5	Arabika PM (dark)	5,5
6	Arabika Pm (Light)	6,0
7	Arabika pm (Medium)	5,7
8	Robusta PM organik (Light)	5,3
9	Robusta pm organik (Dark)	5,1
10	Robusta pm organik (medium).	5,2
11	Robusta pm Natural (Light)	5,3
12	Robusta pm natural (medium)	5,1
13	Robusta pm natural (Dark)	5,1
14	Robusta pm Fermentasi	5,6
15	Librika	5,8

Figure 2. pH Measurement Data for 15 Types of Coffee

Based on Figure 2, which shows that each type of coffee has a different pH value, the activity of measuring coffee pH allows students to observe a scientific phenomenon (Science) related to the concepts of acidity and alkalinity in chemistry. Through this activity, students understand pH as a scientific concept that can be observed and measured empirically. In this activity, students use pH measuring instruments (Technology) and design as well as carry out measurement procedures (Engineering), such as determining sampling steps, using the measuring tools correctly, and maintaining measurement consistency to ensure that the collected data are reliable. This process trains students to think systematically in designing solutions and working procedures. Figure 3 shows the implementation of learning in activity 1.

Figure 3. STEM Activities in pH Coffee Measurement

Based on Figure 3, it can be observed that students actively collaborate to complete the assigned tasks. Each student takes on a specific role within the group, such as brewing the coffee, preparing and assembling the brewing tools, and measuring the pH of the coffee. This collaborative process reflects effective teamwork, where students coordinate their actions, share responsibilities, and support one another in achieving a common goal.

Through these activities, students engage in hands-on learning that integrates scientific experimentation, the use of tools, and systematic procedures. The process of brewing coffee and measuring its pH not only encourages active participation but also fosters communication, cooperation, and problem-solving skills. Overall, the learning activities depicted in Figure 2 illustrate how collaborative, context-based tasks can create meaningful learning experiences and support students' conceptual understanding through shared inquiry and collective effort. Learning does not focus solely on statistical calculations (median) but also emphasizes conceptual understanding through authentic and meaningful experiences.

Activity 2: Organizing the Data

In the next stage, students organized the collected pH values by arranging them in ascending order. Most students completed this task correctly (for example see Figure 4) and began to understand the purpose of sorting data before determining the median.

Task: *Write down the pH data of the coffee, sorted from smallest to largest!*

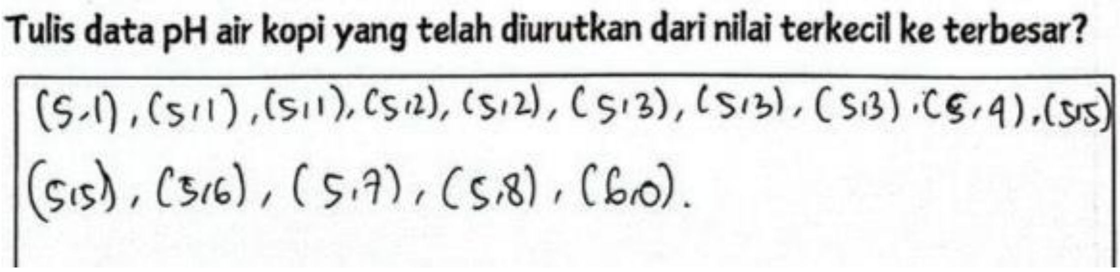


Figure 4. Student Results on Data Sorting Activities

Worksheet analysis showed that nearly all groups were able to produce correctly ordered datasets. Students demonstrated procedural awareness that ordering the data was necessary before determining the median. This indicates that the instructional design successfully strengthened the logical connection between data organization and statistical analysis.

Activity 3: Identifying the Middle Value Informally

After ordering the data, students identified the middle value to determine the median. For datasets with an odd number of values, students were generally able to identify the median correctly. When working with even-number datasets, most students applied the correct strategy of averaging the two middle values, indicating improvement compared to the pilot phase.

Task: *Since there are 15 pH data values, which position in the ordered data represents the middle value? Students' responses to this task are shown in Figure 5.*

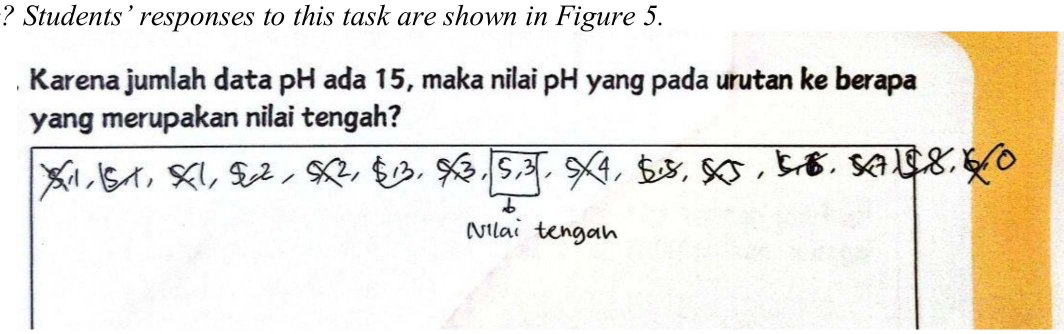


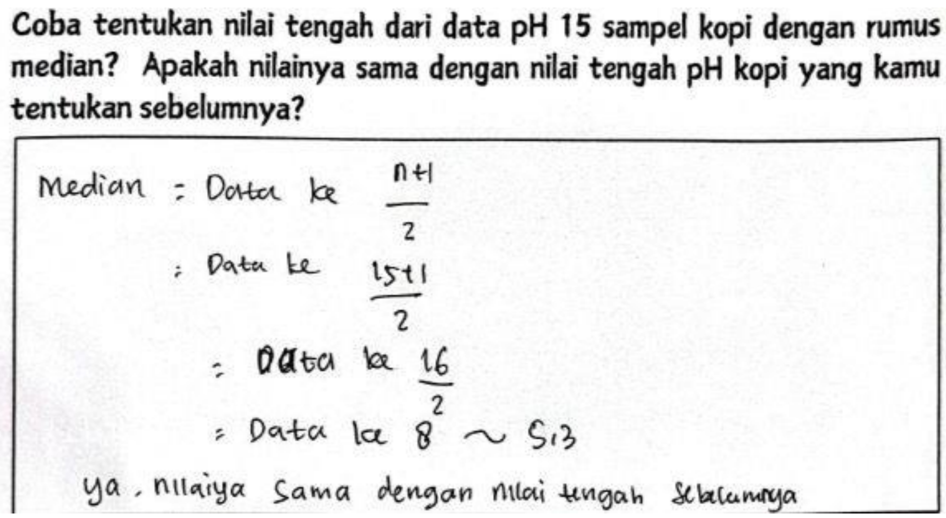
Figure 5. Student Answer About identifying the Middle Value Informally

Students' written responses showed that they were not merely applying a formula but were identifying the "central position" within an ordered dataset. This suggests a shift from procedural execution toward structural understanding.

Activity 4: Formalizing the Median Concept

After identifying the median informally, students were then asked to create a formula in mathematical language to find the median. The purpose of this activity was for students to understand and construct a general formula for finding the median of a data set. Figure 6 shows students' answers related to the activity of writing down the median formula.

Task: "*Determine the median value of the pH data for 15 coffee samples using the median formula. Is the value the same as the median pH value of coffee that you determined earlier?"*


Coba tentukan nilai tengah dari data pH 15 sampel kopi dengan rumus median? Apakah nilainya sama dengan nilai tengah pH kopi yang kamu tentukan sebelumnya?

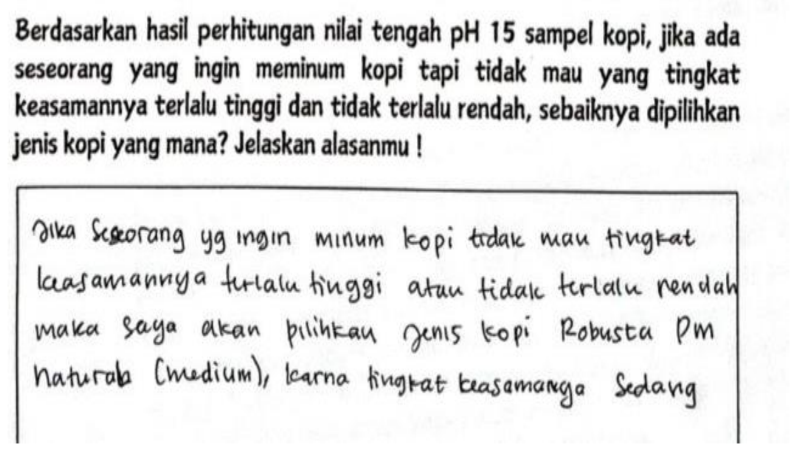
Median : Data ke $\frac{n+1}{2}$
: Data ke $\frac{15+1}{2}$
: Data ke $\frac{16}{2}$
: Data ke 8 ~ 5,3
ya, nilaiya Sama dengan nilai tengah Sebelumnya

Figure 6. Student's Answer About Formalizing Median Concept Activities

Students' written responses in Figure 6 show that they were not merely applying a formula but were identifying the "central position" within an ordered dataset. This suggests a shift from procedural execution toward structural understanding.

Activity 5: Interpreting the Median in Context

In the final stage, students interpreted the median within the context of pH coffee measurement. Many students were able to explain that the median represented the typical or central acidity level of the coffee samples. This can be seen in Figure 7.

 **Berdasarkan hasil perhitungan nilai tengah pH 15 sampel kopi, jika ada seseorang yang ingin meminum kopi tapi tidak mau yang tingkat keasamannya terlalu tinggi dan tidak terlalu rendah, sebaiknya dipilihkan jenis kopi yang mana? Jelaskan alasanmu !** Jika Seseorang yg ingin minum kopi tidak mau tingkat keasamannya terlalu tinggi atau tidak terlalu rendah maka saya akan pilihkan jenis kopi Robusta Pm naturab (medium), karna tingkat keasamanya Sedang	***English version:*** **Task:** Based on the calculated pH values of 15 coffee samples, which type of coffee should be chosen by someone who wants to drink coffee that is neither too acidic nor too weak? Explain your reasoning. **Student's answer**: If someone wants to drink coffee but doesn't want it to be too acidic or too weak, I would choose Robusta Pm natural (medium)

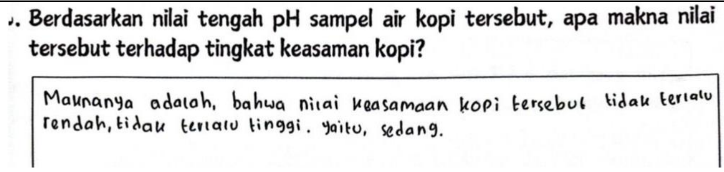
	coffee, because it has a medium acidity level.
 ... Berdasarkan nilai tengah pH sampel air kopi tersebut, apa makna nilai tersebut terhadap tingkat keasaman kopi? Maknanya adalah, bahwa nilai keasamaan kopi tersebut tidak terlalu rendah, tidak terlalu tinggi. yaitu, sedang.	**Task:** Based on the pH value of the coffee sample, what does this value mean in terms of the coffee's acidity level? **Student's answer**: It means that the coffee's acidity level is neither too low nor too high, but moderate.

Figure 7**.** Students Answer about Interpreting the Median Context

Based on the findings from students' responses in Figure 7, it is evident that students were not only able to calculate the median pH from the coffee measurement data but also to interpret the statistical results in real-world contexts. One student stated that "*if someone wants to drink coffee with an acidity level that is neither too high nor too low, then the Robusta PM Natural coffee with a medium level should be chosen*." This statement indicates that students understood the median as representing the "normal" or typical level of acidity of the tested coffee. The recommendation provided by the student was grounded in empirical data obtained from the pH measurements, rather than relying solely on numerical computation. These findings demonstrate students' ability to connect statistical outcomes with meaningful real-life interpretations and to make data-driven decisions.

Post-lesson interviews reinforced the observational findings. Students reported that collecting real data through coffee pH measurement helped them understand the purpose of statistical analysis. Several students explained that arranging the data first made it easier to "see the middle," Students also demonstrated contextual understanding by explaining that a lower median pH indicates that the coffee samples were generally more acidic.

T: "How is the median learning experience using coffee pH measurement activities?"
S: "We gained a lot of new experiences besides learning mathematics. We learned how to use a pH meter, determined the pH levels of various types of coffee, and learned about the different types of coffee from Pagaralam"
T: "Does the learning design make it easier for you to understand the material?"
S: "Yes. It was easier to understand the material because we collected the data ourselves, not just numbers from the book."
T: "Okay, Try to summarize how to find the median of a data set!"
S: "We need to arrange the numbers first from smallest to largest so we can find the middle value"
T: "How do you interpret the pH value obtained from the coffee measurement?"
S: "The pH value indicates the level of acidity of the coffee. The lower the pH value, the more acidic the coffee, while a higher pH value indicates that the coffee is less acidic."

Overall, interview data confirm that students developed not only procedural skills but also conceptual and contextual understanding of the median, supporting the effectiveness of the STEM-based learning trajectory. This result indicates that the contextual STEM activity functioned as a meaningful entry point for statistical learning, especially median concept.

The ALT closely aligned with the intended HLT, although additional teacher scaffolding was required during the transition from informal identification to formal calculation. Overall, the teaching experiment shows that the STEM-based learning trajectory effectively supported students in developing a conceptual understanding of the median. Empirical evidence from classroom observation, worksheet analysis, and student interviews indicates that the integration of coffee pH measurement facilitated students' engagement, procedural accuracy, and contextual interpretation of median concepts. The learning trajectory that emerged can be summarized as follows: 1) Concrete experience (measuring pH)

2) data ordering, 3) identifying the middle value, 4) formalizing the median, and 5) contextual interpretation.

DISCUSSION

The findings of this study indicate that the STEM-based learning trajectory designed through coffee pH measurement effectively supported students' conceptual understanding of the median. The learning trajectory that emerged, from concrete measurement activities to contextual interpretation, demonstrates a coherent progression that aligns with theoretical perspectives on statistics learning and design research.

The initial activity of measuring coffee pH positioned students in an authentic data-generating experience. Empirical evidence from classroom observations and students' written work shows that students were actively engaged in collecting and recording data, which served as a meaningful entry point to statistical reasoning. This finding supports prior research indicating that real-world and experimental contexts enhance students' engagement and conceptual access to abstract statistical ideas (Akiha et al., 2018; Ilyas et al., 2022). Consistent with Retta et al. (2025), who employed water pH as a contextual anchor for learning measures of central tendency, this study confirms that pH measurement activities can effectively bridge scientific inquiry and statistical reasoning. However, the use of coffee as a culturally familiar context extends previous findings by demonstrating that popular and culturally relevant phenomena can further strengthen students' sense-making and motivation.

During the data organization phase, most students successfully ordered the pH values and began to understand the necessity of arranging data prior to identifying the median. This result directly addresses common learning obstacles reported in earlier studies, where students often failed to recognize the role of data ordering in determining the median (Saidi & Siew, 2018; Cazorla et al., 2023). The empirical data show that students' procedural actions were not isolated steps but were increasingly connected to conceptual reasoning, indicating a shift from formula-oriented thinking toward structural understanding. This finding aligns with the conceptual field theory of measures of central tendency, which emphasizes the importance of understanding position and order within a dataset (Cazorla et al., 2023).

The transition from informal identification of the middle value to the formalization of the median represents a critical learning moment in the trajectory. Students' written responses revealed that many students could articulate the idea of "middle position" before expressing it in formal mathematical language. This progression supports the theoretical assumption underlying learning trajectory design that conceptual understanding develops through successive refinements from informal to formal reasoning (Gravemeijer & Cobb, 2006; Akker & Gravemeijer, 2010). Similar patterns were reported in STEM-based learning trajectory studies on proportion and numeracy (Guntur et al., 2023; Putri et al., 2025), suggesting that the staged progression embedded in learning trajectories is effective across mathematical domains.

In the final phase, students' ability to interpret the median within the context of coffee acidity demonstrates a level of statistical literacy that extends beyond procedural competence. Students were able to explain the meaning of the median as a representative or typical acidity level and to use this interpretation to make contextually grounded recommendations. This finding is consistent with previous studies emphasizing that contextual interpretation is a key indicator of meaningful statistical understanding (Utomo, 2021; Zainudin, 2024). Compared with earlier research that reported students' difficulty in interpreting statistical results in real-life situations (Yusuf et al., 2017), the present study shows that integrating STEM contexts within a learning trajectory can significantly support interpretative reasoning.

From a design research perspective, the close alignment between the Hypothetical Learning Trajectory (HLT) and the Actual Learning Trajectory (ALT) indicates that the designed instructional sequence was largely successful in anticipating students' thinking. Minor deviations, particularly during the transition from informal reasoning to formal calculation, required teacher scaffolding. This finding is consistent with prior design research studies, which emphasize the role of adaptive instructional interventions in supporting learning progression (Gravemeijer & Cobb, 2006; Guntur et al., 2023).

Rather than indicating a weakness, these moments highlight the importance of iterative refinement in developing robust local instructional theories. Compared with existing STEM-based trajectory studies that predominantly employ neutral or generalized contexts (Li et al., 2020; Retta et al., 2025), this study contributes a novel perspective by integrating a culturally familiar and socially relevant context coffee into statistics learning. The findings suggest that such contexts not only enhance engagement but also facilitate deeper conceptual and contextual understanding. This supports the PMRI principle of situating real-world contexts as the starting point of instruction, guiding students from concrete experiences toward formal mathematical concepts (Zulkardi & Putri, 2019).

Overall, the discussion of empirical data in relation to theoretical perspectives and previous research demonstrates that the STEM-based learning trajectory developed in this study effectively addresses documented difficulties in learning the median. The findings reinforce and extend prior research on STEM integration, learning trajectories, and statistics education, while offering new insights into the role of culturally meaningful contexts in supporting students' statistical understanding.

This study has several limitations. First, the study involved a limited number of students from a single class, which may restrict the generalizability of the findings. Second, the implementation period was relatively short and focused on a specific context of coffee pH measurement, so further studies with broader contexts and longer durations are needed.

CONCLUSION

This study demonstrates that a STEM-based learning trajectory using the context of coffee pH measurement can supports students' conceptual understanding of the median by engaging them in authentic data collection and analysis, enabling a meaningful transition from concrete experiences to formal statistical reasoning while simultaneously enhancing their statistical literacy and engagement.
The findings imply that statistical instruction benefits from the integration of interdisciplinary STEM contexts that allow students to generate and interpret real data. For classroom practice, teachers are encouraged to incorporate authentic measurement activities and to emphasize the conceptual relationships between data organization and statistical measures. From a research perspective, this study highlights the potential of design research for developing validated learning trajectories in statistics education. Future studies are recommended to implement the designed trajectory in different educational levels and contexts, to compare its effectiveness with non-STEM approaches, and to examine its impact on other statistical concepts such as mean, mode, or data distribution

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DECLARATIONS

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