Designing an Ethnophysics-Based Calorimeter Experiment Using Local Foods from East Nusa Tenggara to Support Students' Science Process Skills

Alfons Bunga Bunga Naen[1], Theresia Wariani[2], Maria Lia Felizarda Freitas[3], Donatus de Fatima Ude[4], Maria Gorette A. da Silva[5], Paulo Alves Cabral[6]

[1,2] Widya Mandira Catholic University, Indonesia
[3,4,5,6] Universidade Nacional Timor Lorosa'e, Timor-Leste

Corresponding author e-mail: alfonsbunganaen1@gmail.com

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ABSTRACT

East Nusa Tenggara (NTT), Indonesia, has culturally meaningful local foods, but their use as objects for measuring energy in physics instruction remains limited. This study develops a blueprint for a simple calorimeter experiment grounded in the ethnophysics of local foods from NTT to support students' science process skills (SPS). It employs a structured, design-oriented conceptual review rather than a systematic review. The corpus comprises 50 sources, including 39 international journal articles, 6 national journal articles, and 5 official or technical documents; 20 sources form the core corpus, while 30 provide supporting evidence. The synthesis proposes non-combustible insulation, standardized sample preparation, calibration of effective calorimeter heat capacity, simple and corrected energy models, a risk matrix, a repeated-measures data sheet, an operational SPS rubric, and an inquiry worksheet. Measured combustion energy is treated as gross experimental energy and distinguished from Atwater-based metabolizable energy. The design is conceptually promising for connecting thermodynamics, local knowledge, and food literacy, but it requires expert validation, safety assessment, practicality testing, and empirical classroom evaluation.

Keywords: Calorimeter; Experimental Design; Ethnophysics; Local Foods; Science Process Skills

INTRODUCTION

Physics instruction on temperature and heat in East Nusa Tenggara (NTT), Indonesia, continues to be dominated by verbal explanations and limited opportunities for students to conduct experiments. This pattern encourages students to view heat transfer, heat capacity, and energy conservation primarily as formulas rather than observable phenomena. Context-based instructional materials on temperature and heat have been reported to help students connect scientific concepts with everyday experience (Astiti & Yusuf, 2018). Students' difficulties in solving physics problems also indicate the need for activities that progressively develop problem identification, principle selection, and evidence evaluation (Yusuf et al., 2022). When standard laboratory equipment is unavailable, opportunities to formulate hypotheses, measure temperature, control variables, and analyze data become even more limited. These conditions highlight the need for alternative experiments that are affordable, safe, contextually relevant, and scientifically defensible.

East Nusa Tenggara has a wide variety of local foods, including jagung bose, katemak, cassava, taro, legumes, marine fish, beef, and free-range chicken. These foods are familiar to students and have documented energy and macronutrient values in the Indonesian Food

Composition Table (Kementerian Kesehatan Republik Indonesia, 2018). Carbohydrates, proteins, and fats store chemical energy that can be released as heat through combustion. In physics instruction, this energy conversion can be observed through the increase in water temperature inside a calorimeter. Using local foods as measurement objects allows students to relate mass, specific heat capacity, temperature change, and specific energy to familiar materials. Local foods therefore serve not only as a cultural context but also as a source of quantitative data for thermodynamic inquiry.

From a pedagogical perspective, integrating local foods from NTT into instruction on temperature and heat is appropriate because the context is concrete, recognizable, and amenable to direct measurement. Context-based learning helps students connect mathematical representations with real-world experience (Astiti & Yusuf, 2018), while dialogue between local knowledge and school science must be conducted critically (Astiti et al., 2024; Zidny & Eilks, 2020). Within Indonesia's Physics Learning Outcomes, the experiment primarily addresses Phase F through the application of thermodynamic concepts and process skills involving observation, questioning, investigation planning, data processing and analysis, evaluation of conclusions, and communication of findings. These foundations are developed progressively from Phase E (Badan Standar, Kurikulum, dan Asesmen Pendidikan [BSKAP], 2025). Unlike ethnophysics objects that are treated only in structural terms, food enables quantitative connections among mass, temperature, energy, nutrient composition, and food security without obscuring the distinction between physics and nutritional assessment.

Previous studies have examined low-cost calorimeters, context-based learning, inquiry laboratories, and food literacy, but these topics have generally developed along separate lines. Calorimetry studies commonly use water, metals, or reactions in solution; ethnoscience studies tend to emphasize the identification of cultural contexts; inquiry research often assesses general learning outcomes; and food literacy research focuses on knowledge and consumption decisions. No blueprint was identified for senior secondary physics that integrates local foods from NTT, instrument specifications, heat-capacity calibration, sample standardization, combustion-risk management, a gross-energy model, a metabolizable-energy reference, an inquiry worksheet, and an operational SPS rubric.

This study aims to develop a blueprint for a simple calorimeter experiment grounded in the ethnophysics of local foods from NTT to support students' SPS. The review addresses three questions: (1) how can an affordable instrument be designed and its risks managed; (2) how can Black's principle of calorimetry be applied through calibration of effective heat capacity; and (3) how can food energy be integrated into inquiry and SPS assessment? The outputs maintained consistently throughout the article are instrument specifications and schematics, sample-standardization procedures, calibration procedures, calculation models, a risk matrix, data-recording formats, an inquiry worksheet, an assessment rubric, and a validation agenda. The proposed design is not intended to replace a bomb calorimeter and does not yet provide empirical evidence of validity, practicality, or effectiveness.

METHODS

This study employed a structured, design-oriented conceptual review. This approach reflects the role of a literature review in mapping knowledge and developing a conceptual agenda (Snyder, 2019), as well as the procedure for building a conceptual framework through concept mapping, categorization, and integration (Jabareen, 2009). The study is not presented as a systematic review because the numbers of initial records, duplicates, and record-level exclusion reasons were not logged prospectively. Searches were conducted in Google Scholar, SINTA, and Scopus and were last updated on August 7, 2026. The main Indonesian-language search string was ("etnofisika" OR "etnosains" OR "pangan lokal") AND ("kalorimeter sederhana" OR "suhu dan kalor" OR "keterampilan proses sains"); the English-language string was ("ethnophysics" OR "indigenous knowledge" OR "place-based science") AND ("low-cost calorimeter" OR calorimetry OR "inquiry laboratory" OR "science process skills" OR "food literacy"). The primary search covered 2018-2026, while earlier seminal sources were retained. The inclusion criteria comprised peer-reviewed articles in Indonesian or English and official documents directly

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relevant to the instrument, thermodynamics, context-based learning, inquiry or SPS, food, curriculum, methods, or safety. Duplicate and irrelevant sources, records with insufficient metadata, and proceedings that were not nationally accredited were excluded.

Table 1. Characteristics of the Review Corpus (Focus Categories are Mutually Exclusive)

Dimension	**Category**	**n**	**Role in the synthesis**
Source type	International journal article	39	Theoretical and pedagogical comparative evidence
Source type	National journal article	6	Indonesian and NTT contexts and local practices
Source type	Official or technical document	5	Food composition, energy, curriculum, methods, and safety
Primary focus	Calorimetry, instrumentation, and food analysis	7	Design, calibration, and measurement
Primary focus	Inquiry, laboratory work, and SPS	13	Instructional sequence and assessment
Primary focus	Ethnoscience, context, and place-based learning	16	Reconstruction of the local context
Primary focus	Food literacy, nutrition, and composition	10	Reference values and interpretive boundaries
Primary focus	Methods, policy, and safety	4	Review transparency and risk control
Corpus role	Core / supporting corpus	20 / 30	Design foundation / supporting evidence and context

The first stage involved modeling the instrument design and formulating the theoretical framework. Materials and dimensions were evaluated in terms of heat capacity, receiver surface area, air gap, heat resistance, stability, sensor access, ventilation, and flame distance. A receiver diameter of approximately 6 cm was selected to provide an adequate collection area without adding excessive thermal mass; an air gap of 1.5-2.0 cm limits conduction; a source distance of 2.5-3.0 cm maintains consistent geometry while preventing the flame from contacting the insulation; and a water mass of 50.0 ± 0.5 g keeps the temperature increase measurable with a school laboratory thermometer. Equations based on Black's principle were then formulated as a simple model and a corrected model incorporating the calibrated C_k. The outputs of this stage were instrument specifications, an assembly sequence, a measurement scheme, a risk matrix, a calibration procedure, and calculation models.

The second stage involved reconstructing the scientific knowledge associated with local foods from NTT. Information on maize, tubers, legumes, meat, and fish was mapped using food codes, raw or processed status, implicit moisture content, and the edible portion (BDD) reported in the Indonesian Food Composition Table (TKPI). Experimental combustion energy was treated as measured gross energy, whereas TKPI values or estimates derived from Atwater factors represented metabolizable food energy. The two were compared only after harmonizing units, mass basis, drying status, and BDD; any difference was treated as a matter for interpretation rather than solely as an instrumental error. The outputs of this stage were a verified food-composition matrix, conversion rules, sample criteria, and interpretive boundaries.

The third stage involved developing the instructional sequence and SPS assessment. The procedure was integrated into guided inquiry through question formulation, hypothesis development, variable planning, measurement, analysis of repeated observations, evidence evaluation, and communication of findings. The indicators were operationalized in Table 2. Two raters independently observe performance using the same rubric, and at least 20% of artifacts or groups are rated by both raters. Before research use, rater training and pilot testing must achieve an intraclass correlation coefficient of at least 0.75 or a weighted kappa of at least 0.60. These thresholds are validation criteria to be tested, not findings of the present review. The outputs of this stage were an inquiry worksheet, evaluation questions, a rubric, and a reliability-assessment procedure.

Table 2. Operational rubric for science process skills

Indicator	Evidence assessed	Score descriptors (1-4)
Formulating a problem	Question in the inquiry worksheet	1 not testable; 2 describes a phenomenon; 3 includes variables; 4 clear, measurable, and contextual
Formulating a hypothesis	Prediction and rationale	1 no prediction; 2 prediction without rationale; 3 reasoned prediction; 4 directional and testable prediction
Planning variables	Work plan	1 incorrect; 2 partially correct; 3 main variables correct; 4 variables, controls, and rationale complete
Measuring and using instruments	Observation sheet	1 unsafe or incorrect; 2 extensive guidance required; 3 correct with limited guidance; 4 independent, correct, and safe
Processing data	Tables, graphs, and calculations	1 incomplete; 2 major errors; 3 correct with minor errors; 4 correct, with complete units and variability measures
Interpreting evidence	Analytical response	1 opinion only; 2 refers to limited values; 3 explains patterns and errors; 4 explains evidence, limitations, and alternatives
Drawing conclusions	Conclusion in the inquiry worksheet	1 inconsistent; 2 partially consistent; 3 answers the problem; 4 answers the problem and appropriately limits the claim
Communicating	Report or presentation	1 disorganized; 2 partial data; 3 coherent and evidence-based; 4 coherent, transparent, and responsive to questions

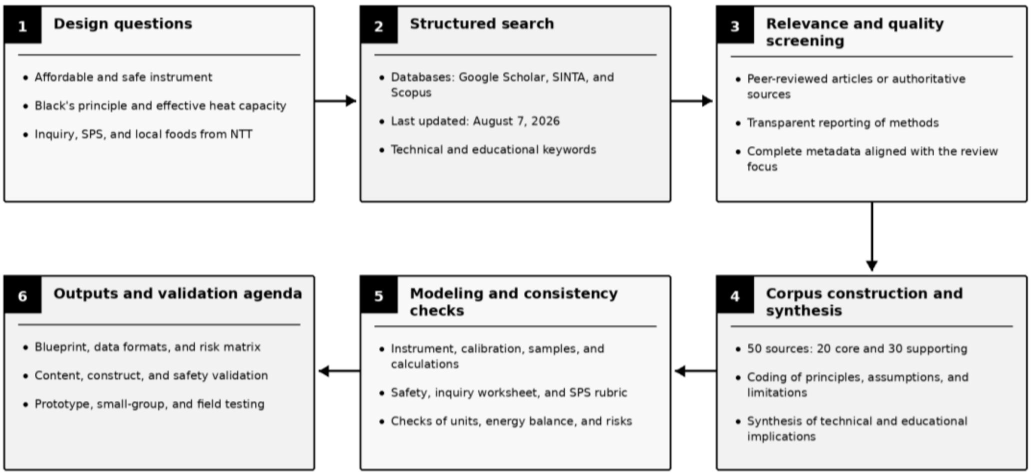

Figure 1. Structured, design-oriented conceptual review workflow

A total of 50 sources were retained: 20 core sources directly related to instrument design, calibration, inquiry, ethnoscience, and food literacy, and 30 supporting or contextual sources. Each source was evaluated according to relevance, peer-review status or publisher authority, methodological transparency, proximity of the evidence to the design decision, and metadata completeness. The synthesis coded recurring principles, divergent assumptions, technical limitations, and educational implications, followed by checks of unit consistency, energy balance, materials, risks, and indicator measurability. Because the initial search-flow data were incomplete, Figure 1 reports only the verifiable process and does not fabricate counts of initial records, duplicates, or exclusions.

RESULTS AND DISCUSSION

The discussion begins by outlining the conceptual design of a simple calorimeter made from repurposed materials and aligned with thermodynamic principles and instructional requirements. The conceptual synthesis proposes a simple calorimeter comprising an aluminum heat-receiving vessel, a metal enclosure, an air gap or non-combustible insulation, a thermometer, a stirrer, a flame and wind shield, and a sample holder. Each component was selected according to its thermal function, stability, safety, and affordability. The proposed configuration is a design hypothesis because its ability to produce consistent, safe, and educationally useful data has not been tested. Instrument specifications, calibration, variable control, and documentation of error sources are therefore positioned as validation requirements rather than evidence of instrument performance.

After establishing the principal components, the following section describes the material specifications and the considerations required to estimate construction costs. The inner vessel is a clean aluminum can approximately 6 cm in diameter and 10 cm in height. The outer enclosure must be made of stable metal, approximately 10 cm in diameter and 14 cm in height; exposed plastic and expanded polystyrene must not be used near the flame. Insulation should consist of a 1.5-2.0 cm air gap or fully encapsulated mineral or ceramic fiber so that students, water, and flame cannot contact it. The flame and wind shield should be made from perforated sheet metal to reduce drafts without obstructing ventilation of combustion gases. The stirrer and sample holder should be made of stable metal wire, while temperature should be measured using a 0-100 °C thermometer or a calibrated digital sensor. Costs should not be specified before an inventory and prototype test because the prices of safety materials, sensors, and fire-suppression equipment vary across schools.

These specifications are then translated into an assembly procedure that maintains component alignment, instrument stability, and operational safety. Assembly begins by making openings in the metal lid for the thermometer and stirrer. The aluminum can is positioned concentrically inside the enclosure with a uniform air gap or encapsulated insulation. A metal shield is installed between the flame and the sides of the apparatus while keeping the combustion-air pathway open. The sample holder is centered 2.5-3.0 cm below the bottom of the can. Before use, the teacher inspects the metal edges, holder strength, instrument stability, sensor depth, stirrer movement, ventilation, and availability of fire-suppression equipment. A prototype that is unstable, exposes insulation fibers, or allows the flame to contact the insulation must not be used.

In addition to material selection, each component must be positioned consistently so that heat transfer and measurement outcomes can be compared across trials. Component placement determines the consistency of heat transfer. The vessel is filled with 50.0 ± 0.5 g of water rather than alternating between volumes of 50 mL and 100 mL. The sensor is positioned at the center of the water volume without touching the wall or base; this position reduces bias from metal conduction and more closely represents the mean water temperature. The sample is placed directly below the center of the can at a fixed distance of 2.5-3.0 cm. The water mass is selected to produce a temperature change large enough to measure while remaining below the 80 °C stopping limit. Stirring is performed slowly using the same pattern and duration in every trial.

Once assembled, the experiment must follow explicit operating and safety procedures from sample preparation through residue handling. The proposed sample-preparation procedure is as

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follows: materials are cut into pieces measuring 5 ± 1 mm, dried at 60 ± 2 °C to constant mass, cooled in a closed container, and stored in an airtight container. Constant mass is defined as a difference of less than 1% between two weighings taken 30 minutes apart. Each trial uses 1.00 ± 0.05 g of material; raw or processed status, storage duration, and mass before and after drying are recorded. These conditions represent an initial working standard that must be validated for each food type. Ignition and combustion follow the RAMP framework, which involves recognizing hazards, assessing risks, minimizing risks, and preparing for emergencies, as well as established academic laboratory safety guidance (American Chemical Society Committee on Chemical Safety, 2017). During initial implementation, the teacher handles ignition, no more than four students use one instrument, and only one operator occupies the marked zone.

This operational design is intended to allow students to measure temperature changes, maintain water mass, control combustion distance, and examine sources of error. Previous studies indicate the educational potential of low-cost calorimeters when uncertainty and instrument heat capacity are analyzed explicitly (Bellin & Lopes, 2025), while digital sensors can improve recording resolution (Lopez, 2020; Potabuga et al., 2025). However, the synthesis does not establish that the proposed prototype is safe or effective. Its educational value and performance can be assessed only after safety inspection, calibration, and small-group testing.

The reliability of the results is also influenced by error sources and heat dissipation during combustion and water heating. Energy loss in a simple calorimeter arises from several concurrent mechanisms. Some of the flame's energy heats the surrounding air and is carried upward by convection before being absorbed by the water. The can surface and flame also radiate energy to the environment. At the same time, the aluminum wall, thermometer, stirrer, and lid absorb some heat, so the energy received by the water differs from the total energy released through combustion. Incomplete combustion leaves char or soot and prevents all of the reacting sample mass from contributing to the measured heat. Uncertainty analyses of educational calorimeters show that vessel geometry, insulation quality, stirring, and heat-capacity corrections must be considered when comparing results across samples (Bellin & Lopes, 2025; Bopegedera & Perera, 2017).

To reduce variation among instruments, each calorimeter must undergo initial calibration before food samples are tested. Each instrument is calibrated before food testing to determine its effective heat capacity (C_k). The cold water and calorimeter are allowed to equilibrate for at least 5 minutes, and their temperatures must differ by no more than 0.2 °C. Hot water is prepared at 60 ± 2 °C, after which the masses of the hot and cold water are measured rather than estimated from volume. Temperature is recorded every 5 seconds for at least 2 minutes before and after mixing. The mixture temperature at the instant of mixing is obtained by extrapolating the linear portion of the cooling curve, thereby correcting for heat loss during the delay in reading. Calibration is performed in triplicate; C_k must be positive and the coefficient of variation (CV) must be no greater than 5%. If these criteria are not met, the sensor position, leakage, stirring, masses, and timing are examined and the calibration is repeated.

$$Q_{\text{lepas}} = Q_{\text{terima}} \quad (1)$$

$$m_{\text{panas}}\, c_w \left(T_{\text{panas}} - T_{\text{mix}}\right) = m_{\text{dingin}}\, c_w \left(T_{\text{mix}} - T_{\text{dingin}}\right) + C_k \left(T_{\text{mix}} - T_{\text{dingin}}\right) \quad (2)$$

In these equations, $c_w = 4{,}184\ \mathrm{J\,g^{-1}\,°C^{-1}}$, T_{mix} is the extrapolated temperature at the instant of mixing, and C_k includes the contributions of the can, lid, sensor, stirrer, and any other component that changes temperature. The mean C_k, together with its standard deviation and CV, is reported for each instrument; values from different groups are not pooled when their constructions differ. Calibration improves the thermal-capacity model but does not correct all heat losses associated with open combustion.

The calibration results are subsequently used to evaluate instrument performance and to establish proportionate limits for experimental accuracy. Open combustion recovers less heat than bomb calorimetry, but this study does not assign an efficiency value before testing. The efficiency range included in an earlier draft was removed because it was unsupported for the geometry, samples, and operating conditions of the proposed design. If efficiency or a recovery factor is to be reported, it must be determined empirically using a reference material, controlled mass and moisture content, a fixed configuration, at least three trials, and reported uncertainty. Until such validation is available, the results should be used to compare trends under identical conditions rather than to determine absolute energy or nutritional values.

Limitations in accuracy can become productive learning resources when addressed transparently. Burned mass is calculated as the difference between the initial mass and the cooled residual mass, while displaced soot or lost residue is recorded as a procedural event. Drying and weighing follow the principles of clearly defining the sample, test conditions, and consistent units (AOAC International, 2023). The difference between experimental gross energy and reference metabolizable energy is not labeled an instrumental error because the two quantities represent different constructs. Students are instead asked to distinguish the contributions of heat loss, incomplete combustion, moisture basis, and physiological differences.

After the technical design has been discussed, the analysis turns to thermodynamic concepts and Black's principle as the basis for energy calculations. Heat is energy transferred because of a temperature difference between a system and its surroundings (Nonti et al., 2024). When a food sample burns, chemical energy stored in molecular bonds is converted into thermal energy through an exothermic oxidation reaction. Part of this energy is transferred to the can, water, thermometer, and surroundings. Under the First Law of Thermodynamics, changes in energy must be analyzed by clearly defining the system boundary and energy-transfer pathways. In the idealized formulation of Black's principle, the heat released by the source is assumed to equal the heat absorbed by the receiving components. The following equation provides the basis of the model, while deviations in the results are used to discuss processes not represented by the ideal assumptions.

$$Q_{\text{lepas}} = Q_{\text{serap}} \quad (3)$$

The mathematical treatment is divided into a simple approach and a thermally corrected approach so that conceptual demands match students' stage of learning. The simple approach emphasizes the direct relationship among water mass, specific heat capacity, temperature change, and combustion energy. The thermally corrected approach incorporates the heat capacity of the apparatus so that the energy balance better represents the real system. The two models are not treated as interchangeable formulas but as a sequence of increasingly complex representations. Comparing their results helps students recognize how assumptions affect the final value. This progression also creates opportunities to discuss model validity, measurement uncertainty, and the limits of generalizing experimental findings.

At the introductory stage, analysis can begin with a simple model that emphasizes the relationship among the heat absorbed by water, temperature change, and sample mass. The simple model neglects the heat capacity of the can and assumes that combustion heat is absorbed only by the water. This simplification is suitable at an introductory stage when the main objective is to understand the direction of energy transfer and the relationship $Q = mc\Delta T$. Students can focus on measuring water mass, initial temperature, final temperature, and the mass of sample burned. The result is then expressed as energy per gram of sample. From the outset, the teacher must explain that 100% heat absorption does not occur in a real instrument. This explanation prevents students from interpreting the result as an absolute nutritional value and prepares them to examine the corrected model.

In this model, all combustion heat is assumed to be absorbed solely by the water:

$$Q_{\text{serap}} = m_{\text{air}}\, c_w\, (T_{\text{maks}} - T_{\text{awal}}) = m_{\text{air}}\, c_w\, \Delta T \quad (4)$$

Experimental combustion energy per unit mass, defined here as measured gross energy, is calculated as follows:

$$E_{\text{kasar,exp}} = \frac{Q_{\text{serap}}}{m_{\text{terbakar}}} \quad (5)$$

For a more rigorous analysis, the thermally corrected model incorporates the instrument's effective heat capacity obtained through calibration. At the advanced level, the effective heat capacity of the instrument is incorporated through the calibrated Ck. This approach is more appropriate than using only the mass and specific heat capacity of aluminum because C_k also includes the lid, sensor, stirrer, and other components that undergo a temperature change. The

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correction improves the completeness of the heat-capacity balance but does not eliminate losses from convection, radiation, soot, or incomplete combustion.
The total heat absorbed by the water and calorimeter is calculated as follows:

$$Q_{\text{serap}} = (m_{\text{air}}\, c_w + C_k)\, \Delta T \quad (6)$$

C_k is determined through mixing calibration and is used only for the same instrument.

$$E_{\text{kasar,exp}} = \frac{(m_{\text{air}}\, c_w + C_k)\, \Delta T}{m_{\text{terbakar}}} \quad (7)$$

The corrected model must still be reported together with its assumptions and uncertainties. The variables and interpretive limits are defined below. To ensure that the calculations are traceable, each variable and standard unit must be defined consistently. $E_{\text{kasar,exp}}$ is expressed in J/g of burned material and must not be described as nutritional energy or specific heat capacity. Q_{serap} is the energy absorbed by the water and calorimeter; m_{air} and m_{terbakar} are expressed in grams; $c_w = 4{,}184\ \text{J g}^{-1}\ {}^{\circ}\text{C}^{-1}$; C_k is expressed in $\text{J}\ {}^{\circ}\text{C}^{-1}$; and $\Delta T = T_{\text{maks}} - T_{\text{awal}}$. All units must be consistent. If the result is converted to kcal/100 g, 1 kcal = 4.184 J is used, and the moisture basis and BDD must match those of the reference source.

C_k is the calibrated effective heat capacity of the instrument, not merely the heat capacity of the can. T_{maks} is determined from the temperature-time curve using the same rule for all trials. Each quantity is reported together with the resolution of the measuring instrument. The simple model may be used to introduce the concept, but the corrected model provides the basis for quantitative analysis; neither converts gross energy into metabolizable energy.

The educational dimension of the design is developed through the integration of ethnophysics, science process skills, and food literacy using local foods from NTT. The ethnophysics approach connects NTT food-processing practices with calorimetry and energy conservation. Drying maize, producing se'i smoked meat, boiling jagung bose, and processing tubers can be examined as processes involving heat transfer and changes in moisture content. Students do not merely memorize the names of local foods; they investigate the physical variables that affect measured energy. The cultural context serves as an entry point for formulating authentic problems grounded in students' experience. The resulting data are then compared with macronutrient composition and theoretical energy values. This relationship allows the laboratory activity to develop SPS while strengthening students' ability to interpret food information critically.

The integration can begin with a set of prompting questions that connect students' everyday food experiences with concepts of heat and energy. Instruction can begin by asking why jagung bose combined with legumes is often perceived as providing longer-lasting satiety than white rice. The teacher can then prompt students to consider what occurs when dried se'i meat, maize, or tubers are burned. A subsequent question focuses on where the energy stored in chemical bonds is transferred during the process. Students are also asked to design a method for demonstrating that one gram of fat theoretically yields more energy than one gram of carbohydrate. Each question is used to identify variables, formulate hypotheses, and determine the data to be collected. The prompts therefore connect local experience, scientific reasoning, and experimental design.

These questions are then translated into a simple calorimetry worksheet that guides students in systematically investigating local foods. The experimental objectives specify the conceptual and procedural outcomes expected from the calorimetry activity. The experiment aims to estimate experimental combustion energy per unit mass, defined as measured gross energy, for samples of local foods from NTT. Students apply energy conservation and Black's principle, control variables, record repeated observations, and interpret uncertainty. The results are compared exploratorily with reference metabolizable energy after harmonizing mass basis, moisture content, food condition, and BDD; this comparison is not used to establish nutritional values.

To achieve these objectives, the measurement procedure is organized so that every quantity in the thermodynamic model is obtained systematically and repeatedly. The measurement procedure applies the principle that energy released by the sample is transferred to the water and calorimeter components. Before combustion, the water mass, initial temperature, sample mass, and instrument condition are recorded. During combustion, the sample position and thermometer depth are kept constant to maintain comparable geometry across trials. The water is stirred slowly to obtain a more uniform temperature. The maximum temperature is recorded immediately after combustion ends. The basic relationship between heat released and heat absorbed is expressed in the following equation.

$$Q_{\text{dilepas}} = Q_{\text{diterima}} \quad (8)$$

A sample that has reached constant mass is weighed to 1.00 ± 0.05 g. The can is filled with 50.0 ± 0.5 g of water. The initial temperature is recorded after stabilization, with the sensor placed at the center of the water without touching the wall or base. Food condition, storage duration, initial mass, and room temperature are recorded before ignition. Missing values must not be reconstructed from memory.

The sample is ignited in accordance with the risk matrix and positioned beneath the center of the can. Temperature is recorded over time while the water is stirred consistently. After the residue has been extinguished and cooled, its mass is measured. Each sample is tested at least three times, and the results are reported as the mean, standard deviation (SD), and $\text{CV} = \frac{\text{SD}}{\bar{x}} \times 100\%$. A criterion of $\text{CV} \leq 10\%$ is proposed as an initial precision threshold for classroom testing and must be validated. Data must not be deleted merely because they differ from other observations; exclusion is permitted only when a procedural error has been documented, and results with and without the excluded value must be reported. If $\text{CV} > 10\%$, the cause is investigated and testing is repeated.

Data are recorded in a format that includes food type, initial mass, residual mass, burned mass, water mass, initial temperature, final temperature, and temperature change. This structure allows every quantity in the equation to be traced to its corresponding measurement. Burned mass is calculated after the sample has been tested, while temperature change is obtained from the difference between final and initial temperatures. Students must use a number of decimal places consistent with the resolution of the balance and thermometer. When measurements are repeated, each trial is recorded on a separate row before the mean is calculated.

The measurement data are subsequently analyzed and compared with food-composition values reported on an equivalent mass basis and for a comparable food condition. Data processing begins by calculating experimental energy from the thermal capacity of the water, the effective heat capacity of the instrument, the temperature change, and the mass of sample burned. In the corrected model, the absorbed energy is calculated from the thermal capacity of the water plus C_k and then divided by the mass actually burned. Results from individual trials are retained before the mean, SD, and CV are calculated. Conversion to kcal/100 g is performed only after harmonizing units, moisture content, food condition, and BDD.

$$Q_{\text{serap}} = (m_{\text{air}}\, c_w + C_k)\, \Delta T \quad (9)$$

$c_w = 4{,}184\ \text{J g}^{-1}\ {}^\circ\text{C}^{-1}$; C_k is expressed in $\text{J}\ {}^\circ\text{C}^{-1}$.

Measured gross energy per gram is calculated as follows:

$$E_{\text{kasar,exp}} = \frac{Q_{\text{serap}}}{m_{\text{terbakar}}} \quad (10)$$

Conversion: $E_{\text{kasar,exp}}\ (\text{kcal/100 g}) = \frac{E_{\text{kasar,exp}}\ (\text{J/g}) \times 100}{4.184}$.

Once experimental energy has been determined, the result is compared with the Indonesian Food Composition Table using an equivalent mass basis and comparable food condition. The reference value is calculated from the carbohydrate, protein, and fat composition reported in the TKPI using Atwater factors (FAO/WHO/UNU, 2004). When composition is expressed as grams per 100 g BDD, the equation directly yields kcal per 100 g BDD. The experimental sample must be converted to a comparable food condition and moisture basis. E_kasar,exp represents the combustion energy captured by the instrument, whereas E_met,ref represents metabolically available energy; the difference between the two cannot be attributed solely to instrumental error. Reference metabolizable energy is calculated using the following notation and basis:

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$$E_{\mathrm{met,ref}} = 4\, m_{\mathrm{karbohidrat}} + 4\, m_{\mathrm{protein}} + 9\, m_{\mathrm{lemak}}\ [\mathrm{kcal/100\ g\ BDD}] \quad (11)$$

After mass basis, moisture content, and units have been harmonized, the exploratory relative difference is calculated as follows:

$$D_{\mathrm{rel}} = \frac{|E_{\mathrm{kasar,exp}} - E_{\mathrm{met,ref}}|}{E_{\mathrm{met,ref}}} \times 100\% \quad (12)$$

The final stage of the worksheet guides students in discussing their findings analytically by considering evidence, uncertainty, and differences in energy basis. Students determine whether $E_{\mathrm{kasar,exp}}$ is lower or higher than $E_{\mathrm{met,ref}}$ and explain the evidence without labeling D_{rel} as a purely instrumental error. They examine convective and radiative heat losses, incomplete combustion, moisture content, residue, uncertainty in mass and temperature, the distinction between gross and metabolizable energy, and the BDD basis. Students then propose testable modifications and predict their effects on the temperature curve, C_k, SD, or CV.

Integrating local knowledge into the experiment provides a meaningful context for conceptual development and scientific literacy. When students recognize the tested materials, they are better positioned to formulate questions and judge whether the measurements are plausible. Context-based learning can also increase personal relevance and encourage stronger engagement than tasks detached from students' lives. The ethno-STEM approach demonstrates that cultural knowledge can be integrated with project and inquiry activities without reducing the demands of scientific reasoning (Sudarmin et al., 2023). Nevertheless, local knowledge must still be critically reconstructed through measurement, source comparison, and evidence-based explanation. This position ensures that ethnophysics extends beyond naming cultural objects and instead shapes how students investigate phenomena.

The food tables retain the names, codes, food conditions, and BDD values reported in the 2017 TKPI (Kementerian Kesehatan Republik Indonesia, 2018). The values represent reference foods available in the national database and do not imply that each food is unique to, or uniformly consumed throughout, NTT. Laboratory samples must be matched to the raw or processed form and moisture condition specified in the table. Energy is not the sole indicator of food quality, and results from simple combustion do not replace nutritional analysis.

To support contextual analysis, the macronutrient composition and energy values of selected local foods from NTT are summarized using TKPI data. Energy and macronutrients in Tables 6-8 are expressed per 100 g BDD for the stated food condition. Food codes and BDD values are included so that students can trace the database records used. The composition of processed foods may differ because of water, coconut milk, legumes, inedible portions, and cooking processes. Data for raw ingredients must therefore not be transferred to a prepared dish without documented recipes, ingredient masses, yield, and moisture content. The first group comprises plant-based local foods representing maize, tubers, and legumes commonly used by communities in NTT.

Table 3. Composition of selected plant-based foods (per 100 g BDD)

TKPI code	Food and condition	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)	BDD (%)	Source
AR016	Yellow maize kernels, dried, raw	366	9,8	7,3	69,1	100	2017 TKPI
AP011	Yellow maize flour	355	9,2	3,9	73,7	100	2017 TKPI
BR016	Cassava, fresh	154	1,0	0,3	36,8	85	2017 TKPI
BR025	Bogor taro, fresh	108	1,4	0,4	25,0	85	2017 TKPI
CR032	Peanuts, dried	525	27,9	42,7	17,4	100	2017 TKPI
CR014	Mung beans, dried	323	22,9	1,5	56,8	100	2017 TKPI

Data on plant-based foods must be interpreted together with cultural notes and compositional assumptions, particularly for dishes such as jagung bose and katemak, whose recipes vary. Jagung bose and katemak are prepared foods with variable recipes. This article no longer presents 150-180 kcal as a TKPI value for these dishes. If the energy of a prepared dish is to be estimated, the mass of each ingredient i is recorded and its energy is calculated as $E_{\text{resep}} = \sum_i \frac{m_i E_i}{100}$; the energy per 100 g of the cooked product is then obtained from $E_{100\text{ g}} = \frac{E_{\text{resep}}}{m_{\text{akhir}}} \times 100$. Assumptions regarding ingredients, coconut milk, legumes, water, edible portions, and yield must be reported. Recipe-based estimates must be labeled separately and must not replace laboratory analysis of the prepared food.

The next group includes locally consumed livestock products from NTT in the fresh condition recorded in the TKPI.

Table 4. Composition of selected meats (per 100 g BDD, fresh condition)

TKPI code	Food and condition	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)	BDD (%)	Source
FR026	Beef, medium-fat, fresh	201	18,8	14,0	0,0	100	2017 TKPI
FR005	Chicken meat, fresh	298	18,2	25,0	0,0	58	2017 TKPI
FR019	Goat meat, fresh	149	16,6	9,2	0,0	100	2017 TKPI
FR009	Lean pork, fresh	371	14,1	35,0	0,0	100	2017 TKPI

The final group presents marine fish relevant to coastal consumption in NTT and available in the TKPI database.

Table 5. Composition of selected marine fish (per 100 g BDD, fresh condition)

TKPI code	Food and condition	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)	BDD (%)	Source
GR019	Skipjack tuna, fresh	107	19,6	0,7	5,5	100	2017 TKPI
GR050	Indian mackerel (oci/kembung), fresh	125	21,3	3,4	2,2	80	2017 TKPI
GR070	Mackerel tuna (tongkol), fresh	100	13,7	1,5	8,0	100	2017 TKPI
GR030	Snapper, fresh	92	20,0	0,7	0,0	100	2017 TKPI

The following discussion interprets the conceptual design in terms of thermodynamic rigor, pedagogy, ethnophysics, SPS, food literacy, safety, and the validation agenda. The first issue concerns thermodynamic rigor and the measurement limits of a simple calorimeter. The corrected model $Q_{\text{serap}} = (m_{\text{air}}\, c_w + C_k)\, \Delta T$ provides a better representation of the instrument's thermal capacity but does not capture all combustion energy. Convection, radiation, soot formation, incomplete combustion, and moisture basis continue to constrain interpretation. The literature on educational calorimeters supports using low-cost instruments to examine assumptions and uncertainty rather than to emulate a bomb calorimeter (Bellin & Lopes, 2025; Bopegedera & Perera, 2017), while a computational laboratory can provide a plausibility check for food-energy estimates (Barbiric et al., 2015). Accordingly, $E_{\text{kasar,exp}}$ is reported as gross energy captured by the instrument and is distinguished from $E_{\text{met,ref}}$.

From a pedagogical perspective, the feasibility of the design depends on the extent to which the laboratory activity supports structured inquiry. Laboratory work becomes meaningful when measurement is connected to ideas, predictions, analysis, and reflection (Abrahams & Millar, 2008; Hofstein & Lunetta, 2004). The guided-inquiry cycle provides support for risky and complex tasks through mass limits, data formats, analytical questions, and teacher checks (Pedaste et al., 2015; Lazonder & Harmsen, 2016). Synthesized evidence on inquiry and laboratory curricula reinforces the importance of guidance, data-based argumentation, and anticipation of teacher workload (Acar Sesen & Tarhan, 2013; Akuma & Callaghan, 2019; Furtak et al., 2012; Minner et al., 2010; Russell & Weaver, 2011). Physical and virtual laboratories can be used in complementary ways (de Jong et al., 2013; Zacharia & Olympiou, 2011). However, potential benefits for conceptual understanding and SPS remain hypotheses that must be examined through practicality testing and classroom studies.

In contextual terms, the integration of ethnophysics positions local foods from NTT as sources of scientific questions and evidence. Local foods from NTT function as sources of questions and quantitative evidence rather than as cultural decoration. This approach is consistent with cross-knowledge dialogue and place-based learning that connect local experience with scientific reasoning (Aikenhead & Jegede, 1999; Chinn, 2007; McKinley, 2005; Snively & Corsiglia, 2001; Zidny & Eilks, 2020; Yemini et al., 2025). The quality of a context depends on its relationship to concepts, experience, motivation, and inquiry rather than merely on the familiarity of the object (Bennett et al., 2007; Gilbert, 2006; Hulleman & Harackiewicz, 2009; Vaino et al., 2012). Reconstruction must remain critical: names, recipes, food conditions, and cultural meanings should be confirmed with the community, while physical claims are tested through measurement. Research on maize-based foods from NTT provides one example of a locally grounded entry point (Silla et al., 2023).

Science process skills are operationalized through indicators linked to observable evidence of performance during the experiment. The rubric links each indicator to evidence in the inquiry worksheet, observation sheet, tables, graphs, calculations, and presentations. Scores must not assess only the final product; instrument use, safety, variable control, and appropriate limitation of claims must also be observed. Double rating and examination of the intraclass correlation coefficient or kappa are required to prevent changes in scores from being confounded with differences between raters. The rubric's quality, reliability, and sensitivity have not yet been established by this review.

In addition to physics concepts and SPS, the experiment is intended to strengthen students' food literacy. The experiment helps students examine how energy values are produced and why food condition, portion size, BDD, and moisture content matter. The literature conceptualizes food literacy as a combination of knowledge, skills, choices, and social context, with varied definitions and attributes (Azevedo Perry et al., 2017; Cullen et al., 2015; Truman et al., 2017; Vidgen & Gallegos, 2014). School programs and adolescents' experiences indicate the need for hands-on activities supported by an enabling environment (Bailey et al., 2019; Brooks & Begley, 2014; Ronto et al., 2016, Ronto et al. 2017), while higher food-literacy scores are associated with better diet quality (Park et al., 2022). Because gross energy and metabolizable energy are not identical, the comparison is used to critique the measurement process rather than to infer food quality or nutritional risk from kilocalories alone.

Classroom implementation requires particular attention to safety and risk management because the experiment uses an open flame. An open flame, smoke or carbon monoxide, hot surfaces, and unstable apparatus are the principal constraints on implementation. Replacing exposed plastic or expanded polystyrene with a non-combustible enclosure and insulation, limiting sample mass, providing ventilation, supervision, personal protective equipment, fire-suppression resources, and stopping criteria can reduce risk but cannot establish safety. The design must be reviewed by laboratory personnel and tested by adults before it is used for demonstrations or group work (American Chemical Society Committee on Chemical Safety, 2017).

Finally, the boundaries of the review must be emphasized so that the conceptual blueprint is not interpreted as empirical evidence of instrument performance or learning outcomes. The outcome of this article is a synthesis and conceptual blueprint, not instrument-performance data or evidence of learning outcomes. The required research sequence comprises content, construct, and safety validation; prototype testing of C_k, recovery factor, SD, CV, and failure modes; small-group testing of time, readability, cost, and classroom management; and field testing using a reliable rubric, implementation data, effect sizes, and qualitative evidence. Only after these stages can the design be judged valid, practical, safe, or effective.

CONCLUSION

This review produced a conceptual blueprint for a calorimeter experiment that integrates local foods from NTT, Black's principle, inquiry, SPS, and food literacy. The revised design specifies non-combustible materials, standardizes the sample at 1.00 ± 0.05 g and the water at 50.0 ± 0.5 g, calibrates C_k, applies a corrected gross-energy model, records repeated observations, incorporates a risk matrix and an SPS rubric, and uses coded TKPI values reported on a BDD basis. The synthesis indicates that the design is conceptually promising as a learning context but does not yet establish that the instrument is accurate, safe, practical, or effective. Development should proceed sequentially through expert and safety validation, prototype testing, small-group practicality testing, examination of rubric reliability, and field testing. Subsequent studies should report SD, CV, uncertainty, procedural failures, implementation fidelity, and the distinction between gross and metabolizable energy.

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