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'KEEP IT HOT' Module: Integrating STEM with Mathematics as the Core Focus through Problem-Based Learning and the Engineering Design Process

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ABSTRACT

Secondary school STEM programmes often underemphasise mathematics, positioning it as a supporting tool rather than a central component of problem solving. This paper introduces KEEP IT HOT, an integrated STEM module designed to reposition mathematics as the foundation of STEM learning. The module combines Problem-Based Learning (PBL) with the Engineering Design Process (EDP) to immerse students in an authentic design challenge: creating a heat-retaining food container. The task requires applying geometric concepts of surface-area and volume optimisation while considering constraints related to efficiency, material sustainability, and thermal performance. Conceptually developed by aligning curriculum expectations with established STEM education frameworks and sustainability priorities, the module integrates science, technology, and engineering around a mathematics-driven optimisation task. It provides structured guidance for teachers and hands-on inquiry for students, addressing common barriers to STEM implementation (e.g., resource constraints and fragmented subject delivery) while fostering 21st-century competencies including critical thinking, creativity, collaboration, and communication. The paper contributes a replicable, mathematics-centred model of integrated STEM instruction and outlines a transparent design-and-development methodology to support future classroom implementation and evaluation. Integrating PBL with EDP purposefully situates scientific and mathematical knowledge within technological design, enabling learners to propose solutions, marshal evidence, and refine decisions through iterative testing.

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STEM integration; mathematics-centred STEM; problem-based learning; engineering design process; optimisation; module design.

1. Introduction

Integrated STEM education has been promoted as a means of fostering interdisciplinary thinking, innovation, and problem-solving capabilities needed to address complex real-world challenges (Bybee, 2013; English, 2016). However, while science, engineering, and technology are often foregrounded in integrated STEM initiatives, research

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repeatedly highlights the marginal positioning of mathematics. Evidence from systematic and integrative reviews suggests that mathematics is frequently used for procedural calculation or post-hoc verification rather than as a conceptual driver that structures inquiry, modelling, and design justification (Goos et al., 2023; Siller & Just, 2022). When mathematics is treated as peripheral, students have fewer opportunities to engage in sustained mathematical reasoning in authentic contexts, and interdisciplinary learning may become activity-driven rather than conceptually coherent.

A useful way to clarify mathematics' function in integrated STEM is to distinguish whether mathematics is positioned as a learning goal or as a tool supporting other disciplinary outcomes. Kristensen et al. (2024), synthesising empirical studies of mathematics in STEM activities, noted that many tasks prioritise engineering artefacts, while mathematical ideas remain implicit, episodic, or conceptually thin. This raises a design challenge for secondary education: how can integrated STEM tasks be structured so that mathematical reasoning is sustained and epistemically central, rather than incidental?

In response, this study presents KEEP IT HOT, a mathematics-centred, integrated STEM module grounded in Problem-Based Learning (PBL) and the Engineering Design Process (EDP). Although STEM–PBL and STEM–EDP models are well represented in the literature, they commonly privilege engineering outcomes or scientific inquiry, with mathematics serving mainly as a supporting resource (English et al., 2017; Fidai et al., 2020). The novel contribution of KEEP IT HOT is its deliberate repositioning of mathematics, specifically geometric optimisation through surface area–volume relationships, as both (a) the primary learning objective and (b) the analytical engine that drives design decisions throughout the inquiry and iteration cycle.

Within the module, optimisation acts as the unifying construct that makes the mathematics–engineering relationship explicit. Students use geometry to define constraints, compare alternatives quantitatively, and justify trade-offs between thermal performance and material efficiency. PBL frames the authentic problem space and the need for evidence-based decisions; EDP structures iterative prototyping and refinement; and mathematics functions as the conceptual link coordinating disciplinary knowledge across these processes. In addition to its theoretical framing, KEEP IT HOT is designed as a classroom-ready resource intended to address practical barriers reported by secondary teachers, such as limited planning time, scarce materials, and uncertainty about interdisciplinary alignment (Jamaluddin et al., 2025; Khalik et al., 2019). Presenting a usable artefact is therefore integral to the research contribution: it demonstrates how mathematics-centred STEM integration can be translated from theoretical advocacy into implementable design.

2. Problem Statement

Despite growing advocacy for integrated STEM education, persistent challenges remain in how mathematics is conceptualised and enacted in interdisciplinary learning at the secondary school level. A substantial body of research indicates that, while science, engineering, and technology are often emphasised, mathematics is frequently positioned as a supporting or procedural subject rather than a central driver of inquiry and design (Goos et al., 2023; Siller & Just, 2022). This constitutes a pedagogical gap: students may complete calculations without sustained Opportunities to build conceptual understanding, develop modelling competence, or use mathematics as an organising framework for problem solving.

In parallel, a practical implementation gap is consistently documented. Secondary teachers report constraints related to limited instructional time, inadequate curriculum-aligned resources, insufficient professional preparation, and uncertainty about how to integrate multiple disciplines meaningfully within existing syllabi (Jamaluddin et al., 2025;

Khalik et al., 2019). These challenges are salient in Malaysian secondary education, where curriculum coverage and assessment demands may limit instructional flexibility. Consequently, even where teachers value integrated STEM, practical barriers can hinder effective classroom enactment.

Although prior STEM integration models frequently draw on PBL and EDP, many implementations prioritise engineering artefacts or scientific investigation, leaving mathematics implicit or secondary (English et al., 2017; Fidai et al., 2020). Taken together, the pedagogical and practical gaps point to a clear research problem: there remains a shortage of mathematics-driven STEM learning designs that are both conceptually rigorous and feasible for secondary classrooms. Addressing this need, the present study undertakes the conceptual design and development of a mathematics-centred, integrated STEM module that positions optimisation as the core disciplinary driver and provides a standards-mapped, classroom-ready resource for teachers.

3. Literature Review

3.1 The Role of Mathematics in STEM

STEM education is widely linked to national innovation, technological progress, and economic competitiveness, and STEM literacy is increasingly framed as essential for sustainable development (OECD, 2018). Mathematics plays a distinctive role in this ecosystem by providing representational tools for quantification, modelling, generalisation, and optimisation. In scientific and engineering practice, mathematical reasoning is not merely computational; it is used to define variables, formalise relationships, justify design choices, and evaluate trade-offs. Yet reviews consistently report that mathematics is often reduced to a technical service discipline within integrated STEM activities used to produce numbers or assess results rather than to structure inquiry and design (Goos et al., 2023; Siller & Just, 2022).

Kristensen et al. (2024), synthesising empirical studies of mathematics in STEM activities, proposed a useful analytical distinction between mathematics as a goal and mathematics as a tool. When mathematics is the goal, mathematical ideas are the explicit learning targets and are revisited for conceptual development; when mathematics functions as a tool, it supports other disciplinary aims and may be applied procedurally. Their synthesis suggests that when mathematics is regarded solely as a tool, the prospects for conceptual retention and transfer are diminished, leading students to perceive mathematics as either episodic or instrumental. Complementary evidence suggests that when design-based STEM tasks make mathematical reasoning explicit through modelling, argumentation, and comparison, students engage in richer mathematical discourse and demonstrate more flexible reasoning (Appelgate and Jurgenson, 2022; Costa & Domingos, 2019).

The marginalisation of mathematics is also shaped by implementation realities. In Malaysia and comparable contexts, teachers report limited time and resources for interdisciplinary planning and uncertainty about how to sustain mathematical focus when activities emphasise creating and testing artefacts (Jamaluddin et al., 2025; Khalik et al., 2019). As a result, mathematics may remain confined to calculation rather than being used for modelling or optimisation. These patterns reinforce calls to move beyond “mathematics in service of science” toward “mathematics as the structuring discipline of STEM", where mathematical reasoning becomes the engine of inquiry and design (Anderson & Makar, 2024).

KEEP IT HOT responds to this literature by positioning mathematics simultaneously as a goal and as a tool. Students are expected to develop understanding of geometric optimisation through surface area–volume relationships (goal) and to use those relationships to justify design decisions that balance thermal performance and material efficiency (tool). In this way, mathematics becomes an epistemic resource that shapes constraints, comparisons, and refinements rather than a peripheral computation step.

3.2 Problem-Based Learning in Mathematics-Centred STEM

Problem-Based Learning (PBL) is a student-centred approach that organises learning around authentic, ill-structured problems and emphasises inquiry, collaboration, and reflective sense-making. Within STEM education, PBL is frequently adopted to support interdisciplinary problem solving, but its contribution to mathematics learning depends on how tasks are designed and what is made assessable. Systematic reviews in mathematics education indicate that well-designed PBL can strengthen conceptual understanding and higher-order thinking when learners are required to justify strategies, interpret data, and evaluate alternatives using mathematical arguments (Aba-Oli et al., 2024; Laine & Mahmud, 2022).

However, the STEM literature also cautions that mathematics can become invisible in PBL environments when the dominant emphasis is on producing an artefact or completing an engineering outcome. In such cases, mathematics may appear only episodically, introduced when calculations are needed, leading to fragmented engagement and limited conceptual growth (Goos et al., 2023; Siller & Just, 2022). Comparative analyses suggest that PBL supports mathematics most effectively when mathematical ideas are explicitly specified as learning goals, revisited across inquiry phases, and linked to criteria for decision-making and justification (Costa & Domingos, 2019).

A further implication concerns assessment. Without structured opportunities to elicit mathematical explanations such as modelling assumptions, optimisation reasoning, or quantitative comparisons, students may rely on trial-and-error design choices with minimal mathematical warrant. This risk is amplified in secondary settings where teachers face curriculum coverage and assessment pressures. Studies of STEM implementation highlight the need for scaffolded design tasks and teacher resources that maintain mathematical visibility while preserving the authenticity of inquiry (Jamaluddin et al., 2025; Khalik et al., 2019). Accordingly, mathematics-centred PBL designs should specify how mathematical reasoning will be evidenced through artefacts such as design logs, comparative analyses, and written justifications.

In KEEP IT HOT, PBL frames an authentic sustainability-orientated problem of reducing material use while maintaining thermal performance and requires students to use optimisation reasoning to justify container designs. This design aims to ensure that mathematical engagement is sustained throughout inquiry rather than being restricted to computation at the end of the task.

3.3 Engineering Design Process in Mathematics-Centred STEM

The Engineering Design Process (EDP) is widely used in integrated STEM education to engage learners in iterative problem solving through phases such as problem definition, investigation, ideation, planning, prototyping, testing, and refinement (Cunningham, 2009; TeachEngineering, 2021). Although EDP provides a coherent organisational structure for STEM activities, research highlights that mathematics-specific functions within EDP phases are often under-specified. Consequently, mathematics may be treated as a secondary support rather than as a central driver of design reasoning (Goos et al., 2023; Siller & Just, 2022).

Authentic engineering practice relies on mathematics across the design cycle: constraints are quantified, variables are modelled, trade-offs are analysed, and optimisation guides decision-making (Moore et al., 2014). When mathematics is confined to later testing phases, students may perceive it as an add-on, and opportunities for modelling and justification are reduced. In contrast, when students are required to use mathematical representations to compare alternatives and justify choices, mathematical engagement becomes more sustained and meaningful (Maiorca & Stohlmann, 2016). Evidence from mathematics-in-STEM research further indicates that explicit mathematical justification supports reasoning flexibility and conceptual learning (Appelgate & Jurgenson, 2022; Costa & Domingos, 2019).

Implementation studies also report that teachers struggle to align design challenges with mathematics curriculum standards, assess mathematical reasoning within collaborative work, and sustain mathematical focus during iterative prototyping (Khalik et al., 2019; Lesseig et al., 2016). These constraints contribute to inconsistent enactment and reinforce the tendency for mathematics to be overshadowed by science or engineering components. Therefore, mathematics-centred EDP designs should make explicit the mathematical functions and epistemic purposes associated with each phase and align these functions with assessable indicators of learning.

Table 1

Mathematics-centred functions of the Engineering Design Process in integrated STEM learning

EDP phase	Mathematical function	Epistemic purpose in STEM learning
Problem identification	Quantifying constraints, variables, and performance criteria	Establishes the problem space through mathematical interpretation of real-world goals and constraints
Investigation	Modelling relationships, estimation, proportional reasoning	Explores design feasibility using mathematical representations and evidence
Ideation	Quantitative comparison, optimisation reasoning	Compares alternatives systematically and selects options using mathematical criteria
Planning	Geometric reasoning, dimensional analysis, scaling	Translates mathematical models into design specifications
Prototyping	Measurement, calculation, data generation	Generates empirical data to test mathematical assumptions and predictions
Testing and evaluation	Data analysis, graphical representation, validation	Evaluates performance against mathematical criteria and identifies deviations
Refinement and improvement	Trade-off analysis, mathematical justification	Guides evidence-based modification to improve efficiency and effectiveness

Note. This table conceptualises EDP as a mathematics-mediated reasoning cycle rather than a purely procedural sequence. Each phase foregrounds distinct mathematical functions that support modelling, optimisation, validation, and justification within integrated STEM learning.

3.4 Integrated STEM Design and Implementation Considerations

Integrated STEM education is defined in multiple ways, but a consistent thread is the intentional connection of at least two STEM disciplines in ways that reflect how knowledge is used to address authentic problems (Nadelson & Seifert, 2017; Moore et al., 2014). However, integration varies in depth. Frameworks describing levels of integration (e.g., multidisciplinary, interdisciplinary, transdisciplinary) emphasise that higher levels require learners to coordinate disciplinary knowledge to address real-world constraints, not merely complete parallel subject activities (English, 2016; Wang & Knobloch, 2018). From a design perspective, the challenge is to preserve disciplinary rigour while enabling coherence across domains.

The literature also documents barriers to implementation, especially in secondary schools. Teachers report limited time for planning, inadequate resources for prototyping, limited professional preparation for interdisciplinary teaching, and uncertainty about assessment in design-based contexts (Jamaluddin et al., 2025; Khalik et al., 2019; Lesseig et al., 2016). Sustainability-orientated STEM tasks introduce additional complexity because they require learners to weigh competing criteria, such as performance and material efficiency, and to justify decisions with evidence. These demands can support meaningful learning, but only if the module provides clear scaffolds and assessment expectations.

Synthesising these strands suggests two design principles for mathematics-centred integrated STEM. First, integration should be discipline-orchestrated: a core disciplinary idea (here, optimisation) should organise inquiry and connect contributions from science, technology, and engineering. Second, modules should be classroom-ready: they should map to curriculum expectations, use feasible materials, and embed assessment that makes disciplinary reasoning visible. KEEP IT HOT is designed with these principles by anchoring the activity in geometric optimisation and by providing structured prompts, success criteria, and alignment between PBL and EDP phases to sustain mathematical reasoning throughout the design cycle.

4. Methodology

This study adopts a conceptual design-and-development approach aimed at constructing a mathematics-centred integrated STEM module grounded in Problem-Based Learning (PBL) and the Engineering Design Process (EDP). Because the purpose is to develop and articulate a classroom-ready module rather than to report classroom outcomes, methodological transparency is provided through an explicit account of the design logic, alignment procedures, and intended validation pathway.

The module development followed three interrelated stages. First, a theoretical analysis was conducted through an integrative review of literature on mathematics-centred STEM integration, PBL, EDP, and sustainability-orientated STEM education. This stage identified persistent gaps in existing practice, particularly the tendency for mathematics to be positioned as a tool rather than a conceptual driver and the implementation barriers reported by secondary teachers. Second, a curriculum alignment stage mapped these theoretical insights to secondary mathematics learning outcomes, with specific emphasis on geometry, surface area, volume, and optimisation. National curriculum expectations and widely cited STEM integration frameworks were consulted to ensure relevance and feasibility. Third, a design synthesis stage translated these theoretical and curricular considerations into a structured module by (a) aligning PBL phases with EDP stages, (b) specifying mathematics-centred reasoning demands at each stage, (c) embedding sustainability considerations as quantitatively reasoned design criteria, and (d) defining assessable success indicators and evidence sources.

As a conceptual development study, empirical validation is outside the scope of this paper. Instead, design validity is established through theoretical coherence with established frameworks, transparent curriculum mapping, and internal consistency of the module's learning objectives, activities, and assessment indicators. The module is presented as a design artefact intended for subsequent pilot implementation and design-based research cycles.

5. Results

Consistent with the conceptual design-and-development methodology, results are reported as structural and theoretical outputs of the module design rather than as empirical learning outcomes. The outcomes include (a) the final structural design of the KEEP IT HOT module, (b) the formal alignment of PBL phases and EDP stages with mathematics-centred reasoning demands, and (c) a mathematics-centred STEM integration model that clarifies mathematics' organising role.

5.1 Structural Design of the KEEP IT HOT Module

The first design outcome is the KEEP IT HOT module itself: a mathematics-centred integrated STEM learning resource designed for secondary education. The module is anchored in an authentic design challenge in which students create a heat-retaining food container with a fixed volume while minimising surface area. This challenge functions as the contextual anchor through which STEM disciplines are integrated. Mathematics is explicitly positioned as the primary learning focus, with optimisation and geometric reasoning (surface area, volume, and proportional relationships) identified as the core learning outcomes. Scientific ideas about heat transfer and insulation serve as supporting knowledge that informs mathematical reasoning, while engineering and technological components provide a context for design, prototyping, and testing.

The module is organised as a coherent learning sequence that guides students from problem orientation and constraint definition to investigation, ideation, planning, prototyping, testing, and refinement. The structure is designed to sustain mathematical reasoning across the entire cycle rather than confining mathematics to isolated calculations. Feasibility is supported by the use of readily available materials and minimal specialised equipment, making the module suitable for implementation in typical classroom settings.

5.2 Formal Alignment of PBL, EDP, and Mathematics-Centred Reasoning

The second design outcome is a formal alignment between PBL phases and EDP stages that makes explicit how mathematical reasoning drives decision-making at each point in the inquiry and design cycle. Table 2 presents this alignment as an epistemic structure, specifying the intended mathematical reasoning focus and the corresponding evidence of learning. This alignment is designed to prevent mathematics from becoming episodic by ensuring that quantitative justification is required during problem framing, comparison of alternatives, evaluation of performance, and refinement.

Table 2
Conceptual alignment of PBL phases, EDP stages, and mathematics-centred reasoning

PBL phase	EDP stage	Mathematical reasoning focus	Evidence of learning
Problem orientation	Problem identification	Defining variables, constraints, and quantitative goals	Articulation of constraints and criteria using mathematical language
Inquiry and investigation	Investigation	Modelling relationships; estimation, proportional reasoning	Use of representations (diagrams, tables) to compare feasible designs
Idea generation	Ideation	Optimisation reasoning; quantitative comparison	Justified selection of an option using mathematical criteria
Solution development	Planning and prototyping	Geometric reasoning, dimensional analysis, measurement	Coherent translation of mathematical models into design specifications
Testing and evaluation	Testing	Data analysis, graphical interpretation, validation	Mathematical evaluation of performance against defined criteria
Reflection and refinement	Improvement	Trade-off analysis; efficiency reasoning; justification	Evidence-based refinement supported by mathematical argumentation

Note. Alignment is conceptualised by epistemic function rather than by activity sequence, highlighting how mathematics governs inquiry, comparison, evaluation, and refinement across PBL–EDP stages.

5.3 Mathematics-Centred STEM Integration Model

The third design outcome is a mathematics-centred STEM integration model that conceptualises mathematics as the organising discipline within integrated STEM learning. In this model, mathematics functions as both a learning goal (explicit outcomes in optimisation and geometric reasoning) and an epistemic tool that structures decision-making, evaluation, and refinement. Science contributes explanatory concepts (heat transfer and insulation) that inform modelling assumptions and interpretation of test data. Engineering provides the iterative design logic through EDP, while technology supports representation and prototyping. Importantly, these domains are positioned as complementary to mathematics rather than as drivers that displace mathematical reasoning. Sustainability serves as the contextual foundation, grounding optimisation in material efficiency and waste reduction.

6. Discussion

This discussion interprets the design outcomes reported in Section 5 in relation to the literature on mathematics in integrated STEM and clarifies the contribution, scope, and limitations of a conceptual development study. No claims are made about student achievement gains or teacher impact because empirical implementation is not reported.

6.1 Interpreting the Structural Design Outcome

The structural design of KEEP IT HOT demonstrates the conceptual feasibility of discipline-orchestrated integration in which mathematics functions as the organising framework for STEM inquiry and design. This responds directly to the recurring critique that mathematics is commonly positioned as a procedural add-on in integrated STEM tasks (Goos et al., 2023; Siller & Just, 2022). By anchoring the module in an optimisation problem and requiring quantitative justification across phases, the design shifts integration from being activity-driven (building an artefact) to being reasoning-driven (using mathematics to define constraints, compare alternatives, and justify trade-offs). This interpretation is aligned with calls for disciplinary authenticity, where students engage with mathematics as it is used in engineering practice through modelling, optimisation, and evidence-based decision-making (Moore et al., 2014).

6.2 Significance of the PBL–EDP Alignment as a Design Result

The formal PBL–EDP alignment (Table 2) can be interpreted as a structural mechanism for sustaining mathematical engagement. In many STEM modules, PBL and EDP are combined procedurally, while mathematics appears late or intermittently. In contrast, the alignment here specifies mathematics-centred reasoning demands and evidence sources at each stage, making mathematical justification a recurring expectation rather than an optional add-on. This design responds to the literature highlighting that PBL supports mathematics most effectively when mathematical ideas are explicit learning goals and are assessed through reasoning artefacts (Aba-Oli et al., 2024; Costa & Domingos, 2019). By treating mathematics as the epistemic bridge between inquiry and design, the alignment also extends prior STEM–PBL/EDP designs that foreground engineering products without clearly articulating mathematics' organising function (Fidai et al., 2020).

6.3 Theoretical Contribution and Differentiation from Existing Models

The mathematics-centred integration model articulated as a result clarifies how existing pedagogical frameworks can be reconfigured to address an established weakness in STEM integration practice. Rather than proposing a new learning theory, the contribution lies in an explicit, transferable design logic: mathematics is positioned hierarchically as the core organiser of reasoning, while science, engineering, and technology provide explanatory and applied resources that remain accountable to mathematically defined criteria. This differentiates the model from 'balanced' STEM integration approaches that aim to weight disciplines equally but may inadvertently dilute disciplinary depth. The proposed logic aligns with recent scholarship arguing for clearer articulation of the function mathematics serves in STEM tasks and for designs that maintain conceptual coherence and assessable mathematical engagement (Anderson & Makar, 2024; Kristensen et al., 2024).

6.4 Scope, Limitations, and Research Trajectory

Because this study is conceptual, its claims are limited to design outputs, theoretical coherence, and curriculum-aligned feasibility. No empirical data were collected; therefore, effectiveness claims regarding student learning, teacher practice, or scalability are outside the scope. Future work should follow a staged empirical pathway. First, a small-scale pilot can examine implementation fidelity, teacher interpretability of the mathematics-centred alignment, and the practicality of assessment artefacts. Second, design-based research cycles can refine scaffolds for mathematical justification and sustainability reasoning based on classroom evidence. Third, comparative studies can examine how discipline-orchestrated integration (mathematics-centred) contrasts with discipline-balanced STEM tasks in relation to mathematical understanding, engagement, and transfer.

7. Conclusion

This study addressed a persistent challenge in integrated STEM education: the marginal role of mathematics within interdisciplinary learning. Using a conceptual design-and-development approach, the study produced KEEP IT HOT, a mathematics-centred integrated STEM module that positions geometric optimisation as both the primary learning goal and the driver of design justification within a PBL–EDP structure. The results demonstrate a coherent design structure in which mathematical reasoning is sustained across inquiry, ideation, prototyping, testing, and refinement, rather than being confined to procedural calculation.

The study contributes to STEM integration discourse by reframing integration as discipline-orchestrated. In this framing, mathematics serves as the epistemic backbone that organises inquiry and governs decisions, while science, engineering, and technology contribute complementary explanatory and applied resources. Practically, KEEP IT HOT is presented as a classroom-ready design artefact that aligns with secondary geometry expectations, uses feasible materials, and includes explicit success criteria and evidence sources to support assessment of mathematical reasoning in design contexts. Because the study is conceptual, claims of impact are intentionally not made; the value of the work lies in design clarity, theoretical coherence, and a transparent pathway for empirical validation.

Future research should build directly from these limitations by implementing the module in classrooms to examine enactment, learning evidence, and teacher decision-making. Empirical studies can also test whether the mathematics-centred model supports deeper conceptual understanding and stronger transfer than models in which mathematics functions primarily as a tool. Overall, KEEP IT HOT offers a principled pathway for elevating mathematics within integrated STEM without sacrificing authenticity or feasibility, strengthening the role of quantitative reasoning in sustainability-orientated problem solving.

Declarations

Acknowledgements
None.

Competing Interests
The authors declare no competing interests.

Ethical Approval
This study did not involve human participants, personal data, or classroom implementation. As a conceptual design-and-development study focused on module construction and theoretical alignment, formal ethical approval was not required in accordance with institutional guidelines.

Author Contributions
Maisarah Abdul Manas: Conceptualisation, formal analysis, writing original draft.
Salbiah Mohamed Hasim: Supervision, conceptual feedback, writing review and editing.
Muhammad Fazdhly Abdul Mutalib: Writing review and editing, contextual and pedagogical input.

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Appendix 1 (The Module)

Module Title : KEEP IT HOT

Level: Upper Primary (Standard 6) / Lower Secondary

Module Objective

Students are challenged to design and construct a **heat-resistant food container** that meets the following criteria:

- Able to maintain the temperature of hot food for a longer period
- Has a fixed capacity of **12,000 cm³**
- Uses the **smallest possible surface area** to minimise material usage

Through this task, students apply **mathematical optimisation**, **scientific understanding of heat transfer**, and **engineering design thinking** to solve a real-world problem.

1.1 Introduction: Contextual Problem

Two real-world issues are presented to engage students:

Problem 1: Excessive use of packaging materials contributes to waste and environmental pollution. **Problem 2:** Many food containers fail to retain heat, causing food to become wet, soggy, and unappetising.

A fast-food company aims to redesign its packaging to address these challenges. The company requires the container to have a fixed volume of **12,000 cm³**, while using the least amount of material and maintaining food temperature effectively.

Task:
Working in groups, students propose the most suitable dimensions and insulating materials for the container. Teachers may introduce the problem using relevant images or examples of existing food packaging to capture students' interest.

1.2 STEM Elements

Science (S):

- Compare and identify effective thermal insulating materials

Technology (T):

- Design and sketch a heat-resistant food container

Engineering (E):

- Construct and test prototypes using selected materials

Mathematics (M):

- Represent containers as cuboid solids
- Investigate how changes in dimensions affect surface area and volume
- Recognise that containers with the same volume can have different surface areas

1.3 Scientific and Engineering Connections

This activity integrates concepts of **heat transfer and insulation** with engineering applications. Understanding thermal insulation supports real-world designs such as insulated houses, winter clothing, refrigerators, food containers, and ovens. Engineering principles guide students in selecting materials and designing efficient structures.

1.4 Learning Objectives

By the end of the module, students will be able to:

- Distinguish between good and poor heat conductors
- Describe modes of heat transfer and identify where heat loss occurs
- Analyse how changes in dimensions affect surface area and volume
- Explain why different shapes with equal volume result in different material usage

1.5 Values and Attitudes

The module promotes:

- Inquiry and curiosity
- Collaboration and teamwork
- Creativity and innovation
- Environmental responsibility

1.6 Duration

Four lessons:

- Lesson 1: **Ask & Imagine**
- Lesson 2: **Plan**
- Lesson 3: **Create**
- Lesson 4: **Improve**

1.7 Group Size

Students work in groups of **3–4**.

1.8 Engineering Design Process

ASK (Engage)

Teachers initiate discussion using real-life examples of fast-food containers (e.g. boxes that become wet or fail to retain heat).
Students identify key problems:

- Excessive packaging waste
- Poor heat retention

IMAGINE (Explore)

Students research and discuss possible solutions, focusing on:

- Minimising surface area while maintaining fixed volume
- Selecting suitable insulating materials
  They produce sketches and initial prototype ideas, followed by trial testing.

PLAN

Students select the most suitable design by:

- Drawing labelled diagrams
- Listing required materials
- Justifying choices mathematically and scientifically

CREATE

Students construct their prototype and:

- Measure temperature changes over time

- Record and analyse data
- Gather feedback from peers

IMPROVE

Students reflect on results and:

- Analyse weaknesses in design
- Modify dimensions or materials
- Improve efficiency and performance

PRESENT & EVALUATE

Groups present their designs, engage in question-and-answer sessions, and receive peer feedback.

1.9 Reflection Questions

Students respond to questions such as:

1. How does thermal insulation reduce heat loss?
2. Which materials are most effective as insulators, and why?
3. How does insulation thickness affect performance?
4. How can mathematics help reduce material usage?
5. How does your design contribute to reducing waste and pollution?

2.0 Teacher's Guide

Overview

The module consists of **two integrated parts**.

Part 1: Optimising Surface Area (Volume = 12,000 cm³)

Students:

1. Compare different cuboid dimensions with the same volume
2. Calculate surface area for each model
3. Record results in tables
4. Identify the most efficient design and justify mathematically

Example: Different Dimensions, Same Volume

Model	**a (cm)**	**b (cm)**	**c (cm)**	**Volume (cm³)**	**Surface Area (cm²)**
1	120	10	10	12,000	5,000

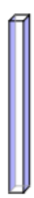
2	60	20	10	12,000	4,000
3	40	30	10	12,000	3,800
4	30	20	20	12,000	3,200

Model description by surface area and volume $12000cm^3$

Part 2: Thermal Insulation Investigation

Students:

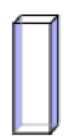
1. Select suitable insulating materials
2. Build a prototype using the optimal dimensions
3. Measure food temperature before and after a fixed time interval
4. Compare temperature loss using different materials
5. Analyse results and refine their design



MODEL 1

$$120cm \times 10cm \times 10\ cm = 1200cm^3$$

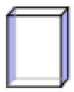
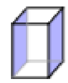
Surface area : $5000cm^2$



MODEL 2

$$60cm \times 20cm \times 10\ cm = 1200cm^3$$

Surface area : $4000cm^2$

 MODEL 3 $40cm \times 20cm \times 10\ cm = 1200cm^3$ Surface area : $3800cm^2$	 MODEL 4 $30cm \times 20cm \times 20\ cm = 1200cm^3$ Surface area : $3200cm^2$

Example: Temperature Change Table

Insulating Material	Initial Temp (°C)	Final Temp (°C)	Temperature Drop (°C)
Material A			
Material B			
Material C			