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The HEAD Foundation

STEM EDUCATION IN CULTURE & CONTEXT

A Handbook for Educators

BOOK 1 | From Frameworks to Familiar Spaces

Acknowledgements

This handbook would not have come together without the generosity, insight, and commitment of the educators, researchers, and practitioners who contributed their time, ideas, and experiences to this publication.

I would like to thank all our contributors for sharing their reflections on STEM education, and for helping us understand how Science, Technology, Engineering and Mathematics can be made more meaningful when rooted in culture, context, and lived experience. Their contributions remind us that effective STEM education is not only about technical knowledge, but also about curiosity, problem-solving, creativity, and relevance to the communities in which students live and learn.

I am especially grateful to Dr Melissa Neo, Academic Planner at InsPIRE, Nanyang Technological University, Singapore, for lending her expertise and guidance to this publication. Her thoughtful input as Consultant Editor helped shape the handbook's focus and ensure that its ideas remain practical, accessible, and useful for educators seeking to bring STEM learning to life in diverse classroom contexts.

Finally, I would like to extend my appreciation to my team at The HEAD Foundation, and in particular to Hillary Loh, Managing Editor, for her careful stewardship of this publication. Her editorial direction, attention to detail, and commitment to the *Making HEADway* series have been instrumental in bringing *STEM Education in Culture & Context* to fruition.

Through this handbook, we hope educators will find ideas, strategies, and examples that encourage them to design STEM learning experiences that are not only engaging and rigorous, but also responsive to the cultures, communities, and contexts of their learners.

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STEM EDUCATION
IN CULTURE & CONTEXT

A Handbook for Educators

BOOK 1 | From Frameworks to Familiar Spaces

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*Bolded subjects indicate the lead discipline, with others being supporting disciplines

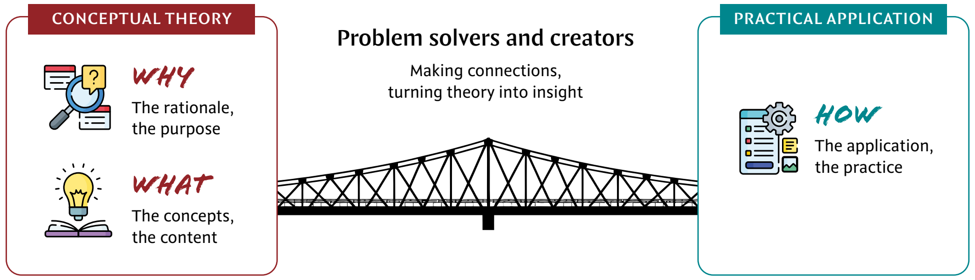
Preface

In the 21st century, technological breakthroughs and advancements drive the demand for a more proficient STEM workforce, resulting in discourse that is increasingly focused on the transformative affordances of STEM education. Structured well, integrated STEM learning can cultivate critical thinking, adaptability, technical literacy, creativity, and innovation, and empower students to tackle complex, open-ended, real-world challenges. The systemic shift towards STEM integration in the educational landscape, whether embedded within the core curriculum or through co-curricular initiatives, provides opportunities for students to contextualise their learning. By bridging conceptual theory with practical application, learners can discern the "why" (rationale) behind the "what" (content) and "how" (application), transitioning students from being passive consumers of information towards becoming problem solvers and creators.

This handbook is a practical companion for practitioners who believe that STEM is not just a collection of disciplinary knowledge and skills, but rather a dynamic culture with a unique ecosystem of its own, shaped by distinct characteristics, frameworks, practices, and societal values.

Bridging Conceptual Theory and Practical Application

Connecting *understanding* with *doing* to create real impact

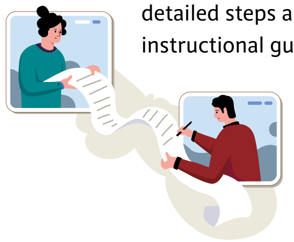


At the heart of this ecosystem is contextualised STEM learning and problem-solving. By integrating cultural narratives, community beliefs, and regional realities into STEM lessons, this approach empowers students to be intrinsically curious and critically engage with and address local and global challenges.

Featuring ready-to-implement lesson plans and comprehensive customisable supporting materials, this handbook provides a diverse portfolio of contextualised lessons spanning early childhood through to higher education. The lessons showcase how practitioners and educators across Asia have integrated region-, school-, and/or community-specific challenges with actionable insights for short-term, single-day STEM initiatives, or long-term project- or problem-based learning.

In each chapter you will find:

Lesson objectives for adoption or adaptation based on your curricula needs



A lesson plan with detailed steps and instructional guidance

Pedagogical tips to facilitate inquiry, guide collaborative discourse, and scaffold complex tasks, etc.

Challenges and solutions to provide insights into potential roadblocks such as resource management and student learning difficulties

Teacher reflections such as on-the-ground experiences, lesson modifications for future iterations, and more!

Book I

From Frameworks to Familiar Spaces

Section 1: Models and Frameworks for STEM Instructional Design

Section 2: Immediate and Familiar Spaces as Sites of STEM Learning

Book II

From Systems to Social Stewardship

Section 3: Using STEM to Model and Understand Systems

Section 4: Cultivating Civic-Mindedness through STEM

> **“STEM is not just a collection of disciplinary knowledge and skills, but rather a dynamic culture with a unique ecosystem of its own, shaped by distinct characteristics, frameworks, practices, and societal values.”**

Given that no two classrooms are identical, we hope that this handbook acts as a:

1. Conceptual foundation to try out integrated, contextualised, STEM lessons; and
2. Launch pad to modify, ideate, or pilot contextualised STEM lessons of your own, that draw out and strengthen student STEM competencies.

To guide your journey, the content has been sectioned into two parts:

- *Book I: From Frameworks to Familiar Spaces*
- *Book II: From Systems to Social Stewardship*

Learn about frameworks developed and enacted by STEM specialists and educators to support pedagogical practices such as inquiry-based learning, design thinking, and problem-based learning. Then, explore how to leverage easily-accessible everyday spaces such as the school environment and local community to anchor technical concepts in familiar real-world contexts. Guide students to recognise the complex, interdependent relationships between technological, environmental, and social structures through predictive modelling and systems-based thinking. Cultivate a sense of civic mindedness, to encourage students to leverage STEM competencies for ethical decision-making and sustainable contribution towards the resilience and wellbeing of their local and global communities.

Learning is deeply shaped by the values, stories, beliefs, and systems of knowledge within each community. Contextualisation of STEM lessons can aid students in:

- Recognising the relevance and application of knowledge to their immediate world;
- Boosting cognitive engagement and conceptual retention; and
- Appreciating how complex problems demand an integrated and interdisciplinary approach, through shared communal value and collaborative ways of thinking and learning.

> **“Learning is deeply shaped by the values, stories, beliefs, and systems of knowledge within each community.”**

We hope that this handbook will serve as a supportive guide as you begin or deepen your journey of integrating STEM education as a cultural practice. It is our hope that the pedagogical frameworks and lesson plans detailed here will provide fresh perspectives that inspire spaces for collective inquiry, co-construction of knowledge, critical consciousness, and innovation; and instil in students the essential competencies foundational to a future-oriented and adaptive mindset.

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Contributors' Biographies

Dr Kessara Amornvuthivorn has led major education initiatives across Southeast Asia since 2005, drawing on 14 years of experience in the private sector and entrepreneurship. Her work focuses on advancing evidence-based policies to strengthen human resource development, especially in basic education. She has also supported nationwide education reforms in Thailand via research at the Teachers College.

She holds a PhD in Development Administration from the National Institute of Development Administration (NIDA), Thailand, and currently serves as Program Director at SEAMEO STEM-ED, guiding regional research and capacity building in STEM education. From 2015 to 2023, she led the USD 35 million Chevron Enjoy Science initiative, which enhanced K–12 STEM education through partnerships with policymakers, universities, and educators. She currently directs the Southeast Asian Teacher Education Programme, a regional collaboration with ministries of education and STEM institutions in five countries.

Dr Burin Asavapibhop currently works at the Southeast Asian Ministers of Education Organization Regional Centre for STEM Education (SEAMEO STEM-ED) as a Programme Manager responsible for STEM resources and capacity building. He has been with SEAMEO STEM-ED since January 2022. He was previously a professor in Physics at Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand where he led an experimental high energy physics research group. He has been involved in several world class experiments such as the Compact Muon Solenoid at the European Organization for Nuclear Research, Switzerland, and the Jiangmen Underground Neutrino Observatory at the Institute of High Energy Physics, China.

Dr Ariel L. Babierra is an Associate Professor of Mathematics at the Institute of Mathematical Sciences, University of the Philippines Los Baños. He obtained his PhD in Mathematics from University of the Philippines Diliman with specialisation in Approximation Theory. His work includes participation in curriculum and instruction committees for the Mathematics and Applied Mathematics programme and teaching a General Education course on Mathematics, Culture and Society. His training in quality assurance for curricular programmes led him to redesign courses to ensure alignment with programme and learning outcomes while incorporating soft and core skills even in highly technical Mathematics courses. In his free time, he can be found reading books about Mathematics or wandering fantasy worlds in books and role-playing games.

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Mdm Rosmiyati Bustami is a dedicated Geography educator at Punggol Secondary School in Singapore with nearly 30 years of teaching experience. She has continually driven innovation to make learning relevant, hands-on, and purpose-driven. In 2022, she and her Geography Unit were awarded the MOE Innergy (Bronze) Award for their Innovative and Sustainable Urban Farming project, marking a key milestone in their collective effort to nurture students as informed, concerned citizens who contribute meaningfully to a sustainable future.

Her efforts showcase the transformative potential of Geography education — when cross-disciplinary partnerships and real-world applications come together to equip students with scientific inquiry skills, technological literacy, and a strong sense of environmental stewardship.

Ms Shella Mae E. Catalan is a Biology teacher at De La Salle University Integrated School, where she has been shaping young minds for the past 10 years. Throughout her decade of teaching, she actively integrated innovative teaching strategies and experiential learning approaches, such as laboratory activities and STEM-based projects. A licensed professional teacher, she is set to further her academic journey by pursuing a Master's degree in 2025, aiming to enhance her expertise in Science education and bring new insights to her teaching practice. Her decade-long career and continued pursuit of academic excellence embody her mission to inspire, educate, and make a lasting impact on her students and the community.

Mr David Chak is a Malaysian educator and social entrepreneur dedicated to revolutionising education. He is the co-founder and curriculum director of Arus Academy, a social enterprise that has impacted over 150,000 students and 100,000 teachers in Malaysia since 2015. A former Teach for Malaysia Fellow, David co-authored the Malaysian Year 5 Digital Technology textbook and writes on global issues and media literacy for a local Chinese quarterly magazine. His expertise is further enriched by several prestigious fellowships: the Young Southeast Asian Leaders Initiative (YSEALI) Professional Fellowship, the Acumen Fellowship, and the Fulbright Hubert H. Humphrey Fellowship at Vanderbilt University. He holds a bachelor's degree in Psychology with a minor in Computer Science from McGill University in Canada and a postgraduate diploma in education from the Northern University of Malaysia.

Dr Chen Liu Qi is a Curriculum Specialist at Science Centre Singapore, where she champions the development and implementation of STEM applied learning programmes across the public school system. She works closely with educators to co-create dynamic teaching resources that bring science to life in the classroom. Driven by a deep passion for environmental sustainability, Dr Chen is committed to inspiring students to engage with real-world ecological issues and become thoughtful stewards of the planet through meaningful learning experiences.

Ms Suparat Chuechote is a Lecturer at the Faculty of Education, Naresuan University. She holds a BSc in Mathematics from McGill University, Canada, and an MSc in Applied Mathematics from Case Western Reserve University, United States. She is currently a PhD candidate in Science and Technology Education at the Institute for Innovative Learning, Mahidol University. She serves as Vice Principal of the Naresuan University Demonstration School (Primary Level) and Program Director of the BEd in Mathematics Education at the Faculty of Education, Naresuan University. Her research interests include Mathematics education, STEM education, Computational Thinking, Educational Data Mining, and Data Management. As a co-founder of Thailand's CME Lab (Critical Mathematics Education), her work explores a wide range of topics, including STEM education, Computational Thinking, and Educational Data Mining.

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Mr Leo Andrei Crisologo teaches Mathematics in the Philippine Science High School — Main Campus and has done so since 2008. He has conducted teacher training programmes on STEM and the Engineering Design Process for public school teachers under the STEM+Ph initiative of Unilab Foundation, the Department of Education, and the Philippine Science High School System. He is one of the writers for the General Mathematics Learning Guides, a project of the Commission on Higher Education K-12 Transition Program to provide ready-made lessons to new Senior High School teachers during the transition. He has served as Curriculum and Instruction Division Chief for the Philippine Science High School — Main Campus from 2017 to 2018. He received his undergraduate and graduate degrees from the University of the Philippines in Diliman. He attended the Indiana University of Pennsylvania as a Fellow of the Fulbright Distinguished Awards in Teaching Program for International Teachers in 2020.

Dr Nor Haniza binti Abdul Hamid holds a Bachelor of Science in Mathematics from the University of Bristol, United Kingdom, a Master of Science in Mathematics Pedagogy, and a Doctor of Philosophy in Mathematics Education from Universiti Putra Malaysia. Currently, Dr Nor Haniza serves as the Research and Evaluation Manager at SEAMEO STEM-ED in Bangkok, Thailand, focusing on regional collaboration, research studies, and program evaluation to advance STEM education in Southeast Asia. She has been leading the development of the research report for the Southeast Asia STEM Education Landscape Study and is now managing the research teams for the Southeast Asian Teacher Education Programme. In addition to research contributions, Dr Nor Haniza serves as an editor for the *Southeast Asian Journal of STEM Education*.

Professor Emeritus Dato' Dr Noraini Idris is the President and Founder of the National STEM Association, President of IMT-GT Uninet STEM, Founder of the Asia Pacific STEM Roundtable (2018), Professor Adjunct at Universiti Malaysia Terengganu and International Islamic University Malaysia, and Advisor to the Universiti Malaya STEM Centre. She obtained her PhD from The Ohio State University, United States, and previously served as Deputy Vice Chancellor (Research & Innovation) at Sultan Idris Education University and Dean of the Faculty of Education at Universiti Malaya.

A Fulbright Research Fellow, she has published widely at national and international levels, and collaborated with UNESCO, the British Council, Australian universities, and the Sumitomo Foundation, Japan. She has presented papers globally and is the recipient of numerous awards, including the Distinguished Diversity Enhancement Award from Ohio State University (the only Asian recipient for the Minority Young Scholars Project), the Graduate Research Alumni Award from Ohio State, and multiple Gold Medals at ITEX and MTE for innovations in assessment systems, teacher education models, and STEM educational modules.

In 2020, she was further honoured with the International Recognition Award for her pioneering efforts in cultivating STEM entrepreneurs.

Dr Thanyaluck Ingkavara is a lecturer at the Faculty of Education, Naresuan University. She was previously a Mathematics teacher at Naresuan University Secondary Demonstration School, Thailand. She worked with middle school students, where she helped them understand Mathematics as a system, and apply it to real-world situations. There is a growing concern about making Mathematics relevant to students' lives and connecting it to other disciplines. Addressing real problems in the local context, while challenging, greatly enhances students' learning. This challenge has led her to focus on Mathematical Education within the STEM framework, particularly on the use of ICT in Mathematics Education.

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Ms Yunyoung Jeong is currently seconded by the Ministry of Education of the Republic of Korea to the Singapore Korean International School, while also serving as a Korean language teacher at a high school in Seoul. She is deeply interested in STEM education and Education for Sustainable Development (ESD), with a strong focus on designing integrated STEM lessons that connect theory to practice and foster interdisciplinary inquiry. She has actively contributed to teacher training and pre-service teacher education through Korea's Ministry of Education's ESD Support Center, and has participated in various national projects aimed at expanding subject-based and experiential approaches to ESD.

Her educational philosophy centres on empowering students to recognise complex social issues and take responsible action. Through project-based learning that integrates STEM, global citizenship, and social responsibility, she aims to cultivate thoughtful, compassionate individuals who bring warmth and positive impact to society through critical thinking and empathy.

Ms Minju Kim is a Biology teacher at Daegu Foreign Language High School in Daegu, South Korea. She holds a Master's degree in Science Education and has a strong professional interest in STEAM education, Education for Sustainable Development (ESD), and creativity-focused pedagogy. As an International Baccalaureate (IB) educator, she integrates global perspectives into her science curriculum, fostering inquiry-driven and interdisciplinary learning. Ms Minju has facilitated numerous professional development workshops for teachers, sharing her expertise and innovative practices. Her deep commitment to designing engaging, future-oriented lessons continues to drive her dedication to inspiring both students and fellow educators.

Ms Honeylen Mei G. Libunao completed her Master's degree in Language Education at the University of the Philippines-Diliman and obtained her Bachelor's degree in Secondary Education major in English at the same university. She is currently the Director for External Relations at the De La Salle University Integrated School and served as the Junior High School English Coordinator for two years and Grade School English and Mother Tongue Coordinator for four years. She has been teaching junior high school and grade school students at the same institution since 2012.

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Ms Nicharee Pramualsab is an English teacher at Starfish School in Chiang Mai, Thailand. She teaches Kindergarten 2 through Grade 2 using an Active Learning approach that fosters a positive environment and engagement. Currently pursuing a Master of Education in Research and Technology in Learning Management, she blends research-based methods with creativity to cultivate curiosity, confidence, and a lifelong love of learning.

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Dr Norazsida Ramli is the President of the Persatuan Sains Bioperubatan Pahang, Vice Secretary of the National STEM Association, and an Affiliate of the Young Scientist Network–Academy of Sciences Malaysia (YSN-ASM). She holds a PhD in Medical Parasitology from the International Islamic University Malaysia (IIUM) and currently serves as Deputy Dean (Student Development and Community Engagement), Kulliyyah of Allied Health Sciences, IIUM. An active advocate for student development, she has mentored students in research, innovation, and community engagement, and was recognised as the Most Transformative Advisor for Student Activity (2023). Regionally, she serves as Secretary and Subject Matter Expert for the Malaysian Professional Development Working Committee under the Southeast Asian Teacher Education Programme. She has facilitated national initiatives including ASM's National Education Reform Regional Workshop (East Coast, 2024), Science Outlook 2025, and MySTIE stakeholder engagements. As programme manager, she led the Pahang Young Scientist Camp (2021) and ASM-East Coast Young Scientist Camp (2023). She also leads the IIUM Street School project supporting homeless children in Kuantan, Malaysia.

Ms Julie Ann R. Santos is a Biology faculty member at the Junior High School level of De La Salle University Integrated School. A licensed professional teacher, she has been in the teaching profession for nearly 13 years, specialising in Biology and other Science domains within the Basic Education Department. She recently completed her coursework for the Master of Science in Teaching Biology at De La Salle University-Manila, as part of her ongoing graduate studies. Her professional expertise includes the development of diverse and engaging Science learning materials, ranging from lesson handouts, modules, and exemplars to laboratory-based activities, aimed at fostering scientific inquiry and meaningful learning among students.

Dr Tan Aik-Ling is an Associate Professor at the Natural Sciences and Science Education department, National Institute of Education (NIE), Nanyang Technological University, Singapore. She is Deputy Head for Teaching and Curriculum Matters at the Natural Sciences and Science Education department. She is also a core team member with the Multi-Centric Education, Research and Industry STEM Centre at NIE, or meriSTEM@NIE. Her research focuses on the scholarship of science teaching and learning, science teacher professional development, and STEM education. She has authored textbooks, activity books, and teaching resources for Singapore's primary school science curriculum.

Dr Teo Tang Wee is an Associate Professor at the Natural Sciences and Science Education department, National Institute of Education (NIE), Nanyang Technological University, Singapore. She is Head of the Natural Sciences and Science Education department and the Co-Head of the Multi-Centric Education, Research and Industry STEM Centre at NIE, or meriSTEM@NIE. An equity scholar in STEM education, her research focuses on issues of inclusivity in classrooms with underachievers and students with special education needs. Tang Wee is the Co-Editor-in-Chief of the journal, *Research in Integrated STEM Education*. She also serves as an editorial board member of *Asian Women* and as Associate Editor of the *Cultural Studies of Science Education*, *Journal of Curriculum Studies*, and the *Asia-Pacific Science Education*.

Ms Retna Widiyasrini is the Assistant Program Manager at Prestasi Junior Indonesia, a non-profit organisation dedicated to advancing education in financial literacy, entrepreneurship, work readiness, and STEM. She leads the STEM education department, designing innovative, inclusive programmes that spark student interest and skills in Science, Technology, Engineering, and Mathematics.

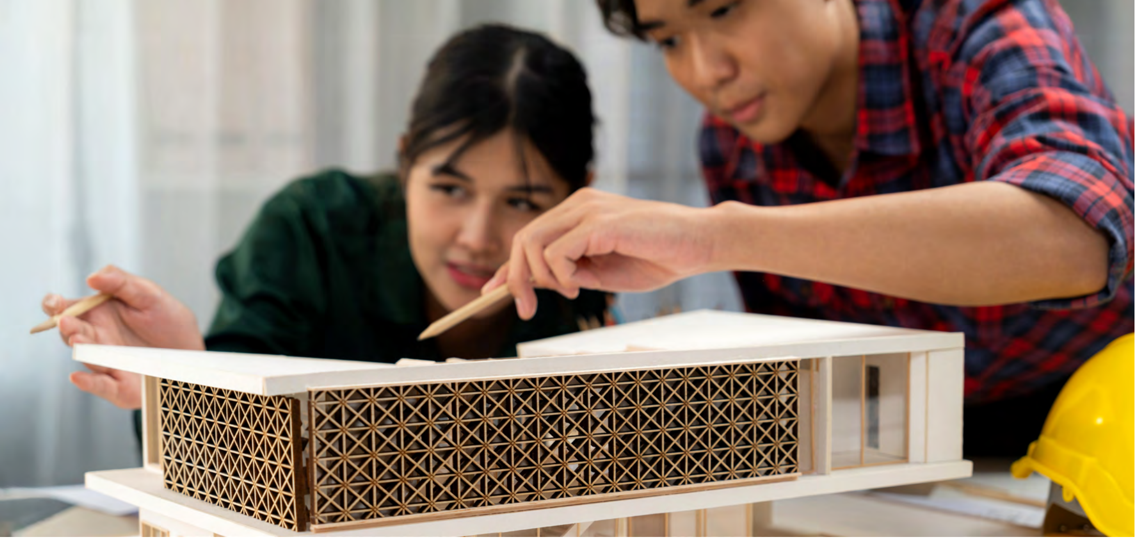
With a strong passion for curriculum development, Ms Retna has spearheaded several impactful initiatives. These include JA RAISE, an AI and robotics-integrated curriculum adopted in four Asia Pacific countries; Street Code, which introduces basic coding to underserved youth; and Robocoder, a digital literacy programme tailored for students with cerebral palsy and other disabilities.

Ms Retna also manages STEM initiatives supported by global partners such as Microsoft, AWS, HP, IBM, Accenture, and the Caterpillar Foundation. Through her leadership, these programmes have expanded access to future-ready learning, reaching diverse student populations across Indonesia and nurturing the next generation of STEM leaders.

Ms Sooprawee Wuttisawat is a primary school teacher at Starfish School, Chiang Mai, Thailand. She teaches English, Problem-based Learning, and Makerspace time. With 17 years of teaching experience, she possesses flexibility in instructional design and a deep understanding of the developmental characteristics of children at different ages. She places strong emphasis on fostering learner-centred education, ensuring that students take ownership of their learning. This approach equips them with essential skills and the ability to apply their knowledge meaningfully in real-life contexts.

CONSULTANT EDITOR

Dr Melissa Neo is a member of the Multi-Centric Education, Research and Industry STEM Centre (meriSTEM@NIE) research team. She is also part of the Nanyang Technological University's Institute for Pedagogical Innovation, Research & Excellence – Teaching, Learning, and Pedagogy (InsPIRE-TLP) unit. A passionate advocate for integrated STEM education, her contributions aim to bridge the gap between theory and practice. Dr Melissa has co-authored *Becoming a STEM Teacher: My Learning Journey* — a self-guided handbook designed to support educators on their path from novice to confident STEM practitioners. She has also served as a judge on several STEM capacity-building symposiums and played a central role in organising the annual Empowering STEM Education Professionals Programme. Her commitment towards creating impactful educational materials and learning experiences is further fuelled by her keen interest in classroom-based research on effective teaching strategies and best practices.



Introduction

Understanding & Applying iSTEM for the Classroom

Coined in the 1990s by the National Science Foundation, the acronym STEM (Science, Technology, Engineering, and Mathematics) has exerted significant influence on contemporary educational discourse over the recent decades, driving global institution-wide impact on educational policy and economic strategy.

While traditional school curricula historically compartmentalised these disciplines into rigid silos, modern STEM education — propelled by an increasingly automated, information-driven economy — has shifted towards an integrated approach. The motivation to integrate STEM is, in part, due to the contrast between the segregated structure of STEM within schools and the integrated STEM-based challenges students encounter underprepared as they enter the workforce.[1] As such, this pedagogical approach aims to cultivate an interdisciplinary mindset, enabling students to connect theoretical knowledge with the broader world, and to understand when and how to apply cross-disciplinary knowledge and practices effectively.

In this handbook, we define integrated STEM (iSTEM) as *"the approach to teaching the STEM content of* ***two or more STEM domains****, bound by* ***STEM practices*** *within an* ***authentic context for the purpose of connecting these subjects*** *to enhance student learning"* (p. 3).[4]

There are various interpretations of what integrated STEM (iSTEM) entails in the literature, offering diverse ways in which iSTEM is operationalised in educational settings. This presents challenges for educators seeking to implement iSTEM be it at the level of a class, unit, or lesson, due to the lack of a universally accepted understanding.

We highlight six characteristics of iSTEM adapted from Kelley and Knowles' 2016 framework, which are exemplified in the lessons highlighted in this book:

1. A complex, persistent, and extended real-world problem[2]
2. Interweaving the knowledge and processes of two or more specific STEM disciplines to solve the problem[2]
3. Engagement in engineering design or design
4. Establishing explicit connections between real-world contexts and STEM content
5. Engagement in authentic STEM practices (such as problem-solving with multiple solutions, evidence-based data collection and reasoning)
6. Development of 21st-century skills (such as critical thinking, equitable participation, and open mindedness towards diverse perspectives)[3]

Effective classroom practice of iSTEM relies on iterative engagement in planning, strategic execution, reflective practice, and refinement. To assist in managing this cycle, we outline some common instructional tensions and decision-making opportunities experienced by teachers.[5] These considerations are intended to prompt deeper reflection on how you might enact iSTEM in your specific educational context.

Balancing curricular content with an integrative approach

Balancing the need to teach subject-specific content deeply and the importance of highlighting the broader interconnections between supporting disciplines. Choose which discipline serves as the primary anchor and which play a supporting role. One can still meaningfully integrate two or more subjects in a lesson to support student conceptual understanding and/or skill development. For example, to evaluate students' understanding of energy transfer (Physics — lead discipline), students build a mini turbine using blades of different shapes (Engineering design — supporting discipline) to measure the voltage output (Mathematics — supporting discipline).

Deciding on sole instructor, parallel teaching, or collaborative teaching efforts

The scope of STEM inquiry can be influenced by a teacher's expertise. When designing a lesson plan, reflect deeply on the complexity of cross-disciplinary knowledge and skills required to address the problem. Then, consider how collaborative instructional methods such as parallel teaching or co-teaching can be intentionally deployed to support student learning given scheduling constraints, student readiness, availability of instructional resources, and more.

Providing guided instruction versus student-directed learning

Open-ended inquiry and complete autonomy can be overwhelming. Students engaging in STEM for the first time frequently feel underprepared, encountering high cognitive load due to gaps in foundation knowledge and technical skills. To mitigate this frustration without diminishing the inquiry process, strategic scaffolds such as embedded time buffers can be put in place — to provide space for unguided trial-and-error, navigate design failures, and engage in iterative troubleshooting. Following this, guided instruction (such as a partially completed script for a coding task) can be provided to bridge the gap between open-ended inquiry and overwhelming frustration.

Encouraging collaboration while supporting individual student needs

Designing an iSTEM lesson that both cultivates a collaborative ecosystem and sheds light on the unique blueprint of individual learners can be challenging. By designing a real-world challenge that is too complex for individual students to solve, this encourages students to embrace diverse perspectives and skillsets to brainstorm solutions, divide problem-solving tasks, and collaborate to converge on an optimal solution. To support individual growth, differentiated roles and layered scaffolding can be tailored to students' skill levels and learning styles.

The interdisciplinary nature of iSTEM functions much like a pulley system, in which the individual disciplines serve as interconnected cords. When collectively pulled by teachers, students, and industry experts, these cords create the necessary leverage to enhance student understanding.[4]

In the same vein, rather than offering a prescriptive model, the presented considerations emphasise the need for continued exploration and empirical insight into iSTEM pedagogy.

This handbook hopes to support individual professional growth while encouraging a broader collaborative exchange within professional learning communities, by translating classroom experiences into research-informed findings and promoting shared inquiry with the wider educational community.

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Section 1

Models and Frameworks for STEM Instructional Design

The chapters in this section feature conceptual models and frameworks developed by STEM education experts, curriculum developers, and practitioners. Spanning a wide range of developmental years from early childhood to K-12 and higher education, the models or frameworks offer different lenses through which STEM educators of varying comfort levels and experience can:

1. learn about,
2. select from,
3. adapt, and
4. learn beyond

during their STEM teaching and learning journey.

Collectively, these chapters demonstrate how STEM education can be implemented across diverse educational contexts and school systems, be it for a single class or within broader systemic constraints such as national curricula. The section offers structurally clear, systematic approaches to guide the instructional design of constructively-aligned STEM lessons founded upon student STEM capacity and competency development. Each chapter provides the language necessary to design a coherent and integrated STEM lesson to move away from siloed teaching towards multidisciplinary learning experiences and beyond.

When reading this section, consider:

- Which of these models or frameworks align best with your current school culture?
- What is the purpose of your STEM lesson? Are you looking to build students' STEM capacities early into their learning years? Do you wish to create a high-energy STEM learning experience?

1.1

Refining and Applying the STEM Quartet Instructional Framework

Associate Professor Tan Aik-Ling & Associate Professor Teo Tang Wee

INSTITUTIONAL PROFILE

meriSTEM@NIE, Nanyang Technological University

LOCATION
Singapore

TYPE OF INSTITUTION
Teacher education college

GRADE LEVEL
K-12 and Tertiary

In this chapter, we learn:

- ✓ Core components of the STEM Quartet Instructional Framework, as a means to connect disciplinary learning outcomes with complex, persistent, and extended problems
- ✓ How to identify complex, persistent, and extended problems; and how to map the strength of interdisciplinary connections
- ✓ The three variations of the STEM Quartet Instructional Framework: problem-centricity, solution-centricity, and user-centricity
- ✓ Examples of the three variations of the STEM Quartet Instructional Framework in a lesson

Planning meaningful integrated STEM learning experiences can be challenging because teachers are typically experts in only one or two disciplines. There are few teachers who have expertise in all four disciplines of STEM. Yet, in integrated STEM learning, teachers are required to be familiar with the conceptual, epistemic, and social norms of the four disciplines. This leads to fear and reluctance in embracing integrated STEM learning. Additionally, teachers are concerned about students' learning of the disciplinary content described in the syllabus. These difficulties, together with unfamiliarity with integrated STEM learning, have resulted in the uneven and lower adoption of integrated STEM in schools.

The STEM Quartet Instructional Framework (henceforth *Quartet)* was designed and proposed by Associate Professors Tan Aik-Ling, Teo Tang Wee, and colleagues in 2019[1] to provide a visual thinking frame for teachers to connect disciplinary learning outcomes with complex, persistent, and extended problems.

The *Quartet* intentionally focuses on **vertical learning within disciplines** and **horizontal connections across disciplines.** By identifying the disciplinary knowledge and connections across disciplines when students work on solutions to a problem, the *Quartet* enables teachers to pinpoint the lead disciplines and collaborate in teams on areas where their knowledge is lacking.

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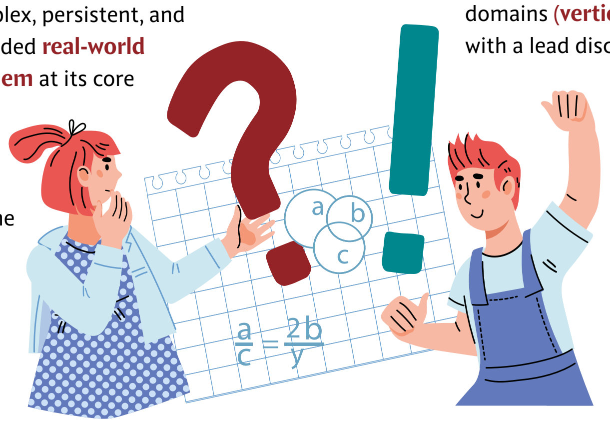
[1] Tan, A. L. Teo, T. W., Choy, B. H., & Ong, Y. S. (2019). The STEM Quartet. *Innovation and education*. 1(3), 1–14. http://doi.org/10.1186/s42862-019-0005-x.

A. Understanding the STEM Quartet Instructional Framework

The *Quartet* has four key characteristics:



01
Problem-solving as the overarching process

02
Complex, persistent, and extended **real-world problem** at its core

03
S-T-E-M as the four disciplinary domains (**vertical learning**) with a lead discipline

04
A focus on connections between the disciplines (**horizontal connections**)

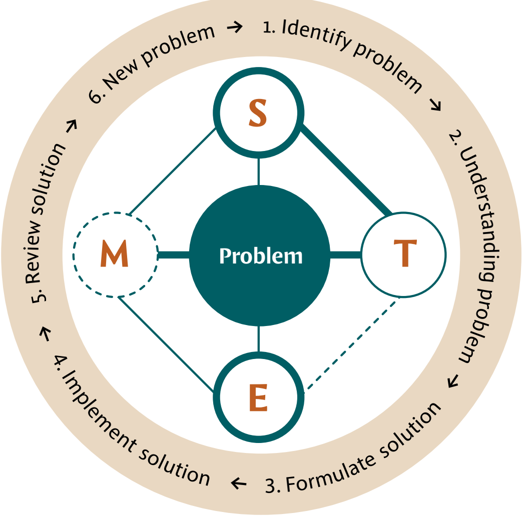
SCAN TO READ
More about the STEM Quartet!

i. Problem-solving

Problem-solving is chosen as the overarching process to encapsulate STEM as it lies at the heart of all disciplines and can be argued to be the centre of the more human-centric and problem-solving approach of **design thinking**.

This visualisation of the *Quartet* shows the connections within and between each STEM discipline and their relationship to the problem and the problem-solving process. We will run through how to interpret this diagram in section Aiii.

Collaborative problem-solving is integral to an integrated STEM curriculum.[2] As such, the problem-solving process forms the overarching frame in the *Quartet*.



The STEM Quartet Instructional Framework

LEVELS OF CONNECTION

▬ Strong
― Moderate
- - - Weak

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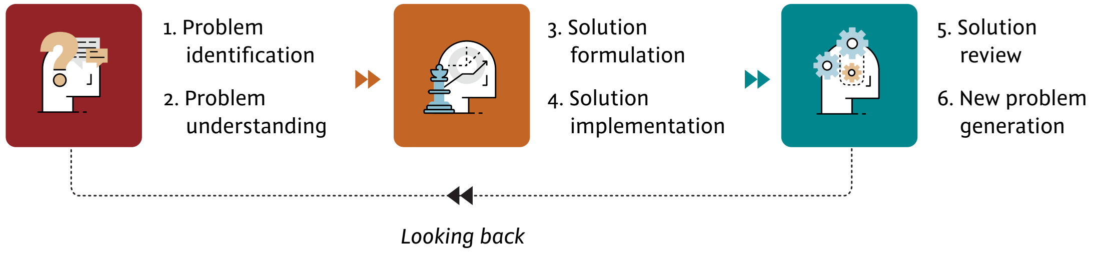
[2] Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research.* Washington, D. C.: The National Academy Press.

We view problem-solving as a generative process that is common to all core disciplines in STEM[3]. The phases of a generative problem-solving process include:



The last phase, **new problem generation**, is similar to Polya's four-step approach[4] to problem-solving, where the last stage is **looking back**. Looking back goes beyond checking whether the solution is right or wrong; it also involves reflecting on the solution's feasibility, potential for extension of problem/solution, and problem-finding. This step of new problem generation, or looking back, is absent in many of the problem-solving curricula.

Engagement with problem-solving allows learners to appreciate how knowledge and skills across disciplines are interconnected, both in terms of the synergies as well as tensions. The interconnected network of different domains of knowledge and skills encourages alternative approaches, refinements of proposed solutions, as well as application of relevant referent-centred knowledge to solve problems. In this way, students learn problem-centred knowledge related to specific contexts rather than accumulate isolated problem-solving skills.

KEYWORD

Referent-centred knowledge refers to knowledge (such as facts and descriptive information) that is specific to a particular topic, concept, or object.

ii. Authentic problem core

The characteristics of the problem core in the *Quartet* are distinct from those of problem-based learning (PBL). In PBL, it is instrumental that problems are authentic and novel, and that minimal guidance is given to the learners in the problem-solving process[5].

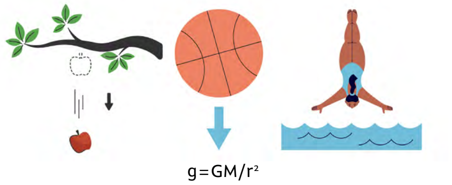
In the *Quartet*, the authenticity of the problem is defined by its practical worth and its relevance to general Science, Mathematics, Technology, or Engineering principles. Guidance will be provided in the form of questions and information given to the learners. The problems of the *Quartet* are characterised by being **persistent**, **complex**, and **extended**[6].

Identifying persistent, complex, and extended problems

Persistent problems

Persistent problems are problems that recur often and, hence, can serve as "organising points for knowledge."[7] Persistent problems extend beyond routine, everyday basic problems that appear in worksheets that are forgotten once students' engagement with the task is over. Instead, persistent problems are problems or explanations that can be applied across multiple contexts.

For instance, rather than simply observing an object "falling," learners should connect that observation to the concept of "gravity." This ability to shift from specific observations to broader concepts enables the transfer and application of learning.



Complex problems

The **complexity** of a problem refers to **requiring the knowledge and ideas from at least two of the four STEM disciplines to solve it**. It is also likely that knowledge and skills from other disciplines are involved, such as language and aesthetics. Additionally, complex problems do not have a single, obvious answer. Problems that can be solved by knowledge from only one discipline would not be considered complex from the perspective of integrated STEM.

Examples of complex problems are climate change, food security, and access to clean water. The 17 areas highlighted in the United Nations Sustainable Development Goals are excellent starting points to prompt discussions on complex problems.

Extended problems

Lastly, problems presented to students should be extended. **Extended problems, while challenging and realistic**, should be scoped in such a manner that allows them to be **solvable within the available curriculum time**. Extended problems require more curriculum time for students to be engaged with the problem, have discussions with their peers to make sense of the problems, and be involved in the evaluation of underlying principles to generate solutions.

An example of an extended problem for primary schools is how janitors who clean the school canteen are often wet from the water sprays, yet it is too warm to wear a raincoat. How can we help the cleaners stay dry and cool?

An example of an extended problem for secondary schools is oil spills, where both large-scale and small-scale spills cause damage to life and property. How can oil spills be cleared quickly to reduce the damage they cause?

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[3] Lester, F. K., & Kehle, P. (2003). From problem-solving to modelling: The evolution of thinking about research on complex mathematical activity. In R. Lesh & H. M. Doerr (Eds.), *Beyond constructivism: Models and modelling perspectives on Mathematics problem-solving, learning, and teaching* (pp. 501–517). Mahwah, NJ: Erlbaum.

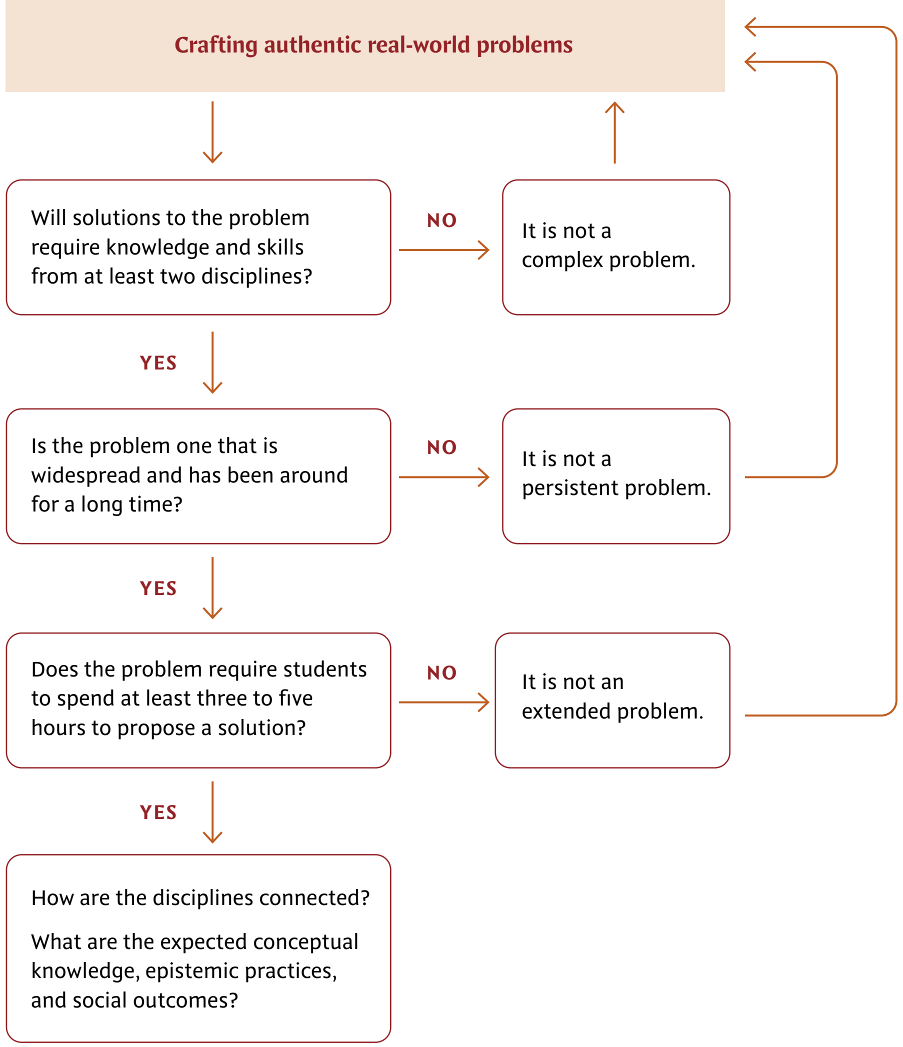
[4] Polya, G. (1945). *How to solve it: A new aspect of mathematical method.* New Jersey, USA: Princeton University Press.

[5] Hung, W. (2009). The 9-step problem design process for problem-based learning: Application of the 3D3R model. *Educational Research Review*, 4, 118-141.

[6] Bereiter, C. (1992). Referent-centred and problem-centred knowledge: Elements of an educational epistemology. *Interchange*, 23(4), 337-361.

[7] Ibid.

Use the decision-making matrix below to help you craft a persistent, complex, and extended problem!



Flowchart for identifying an authentic, persistent, and complex real-world problem to create a STEM lesson

iii. Vertical learning and horizontal connections

We emphasise S-T-E-M as four disciplinary domains from which the knowledge and skills are required to generate solutions to the problem. Each discipline is characterised by unique epistemic practices and knowledge that learners pick up. At the same time, it is important for learners to be familiar with how the knowledge and practices of the disciplines interact.

In many ways, the *Quartet* is similar to the idea of a quartet in music. In music, a quartet consists of four parts, namely, the soprano, alto, tenor, and bass. These four parts work together to produce rich and melodious sound. While each of the parts can technically still make music on their own (just as Science, Technology, Engineering, and Mathematics are legitimate disciplines on their own), the sound that is produced individually lacks richness and harmonic depth when compared to that of a quartet. In a quartet, each part harmonises with the other three to produce a unified sound. Different mechanisms are utilised to produce that unified sound. For instance, in some songs, the melody may be carried by the soprano section with harmonic support from the other three parts; while in other songs, the tenors might assume the primary melodic line.

As with a musical quartet where one section produces the melody with the support of the other sections, **the *Quartet* has a lead discipline**. A problem can be designed to focus on one of the four disciplines as the dominant or lead discipline, with the other three disciplines providing the necessary skills and knowledge for problem-solving.

KEYWORD

Epistemic practices are the methods and processes through which students construct, validate, and communicate the knowledge learnt. Rather than simply acquiring content knowledge, epistemic practices emphasise how students learn and justify their understanding of disciplinary knowledge.

This brings us to how the *Quartet* demonstrates the **vertical learning** and **horizontal connections**.

Vertical learning is characterised by the deep conceptual and epistemic learning within **a single discipline**. For instance, this could be the learning of the concepts of photosynthesis in Science or algebraic equations in Mathematics, or the learning of epistemic criteria for determining the soundness of a scientific claim or a mathematical proof.

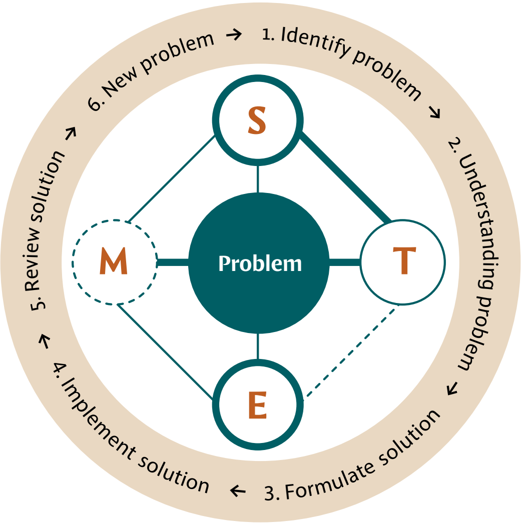
- If the problem requires scientific knowledge and skills to solve, and consequently provides learners with opportunities for in-depth learning of scientific concepts or epistemic criteria valued in Science, a thick circle encloses the discipline indicating steep disciplinary learning.
- If the problem requires the students to merely apply simple mathematical computation to solve the problem, the students are not engaged with in-depth specific mathematical concepts or epistemic criteria valued in Mathematics. As such, the disciplinary learning in Mathematics is limited and denoted by a dotted circle.

Horizontal connections refer to the **links between disciplines**. Connections include application of scientific explanations to make trade-offs between criteria and constraints of an engineering design issue; using appropriate technological tools to enable mathematical modelling; and having embedded sensors to provide information to optimise design in Engineering.

The connections between the four disciplines can be strong, moderate, or weak, as denoted by the thickness of the connecting lines.

- A **strong connection** is reflected by the meaningful synergy of conceptual and epistemic aspects between disciplines.

  For instance, if students were tasked to build a pedestrian bridge commissioned by a client, they would require Science and Engineering concepts such as determining stability when supporting a load, properties of materials (e.g., stress, strain, and expansivity), types of bridge designs, as well as the epistemic practices of making evidence-based decisions (in Science and Engineering), evaluating trade-offs between various criteria and constraints (in Engineering), such as stability, material strength, building cost, and client needs[8]. As such, the connection between the disciplines will be strong and denoted by a thick line.



The STEM Quartet Instructional Framework

- A **moderate connection** is denoted by a thinner line and reflects cross-disciplinary synergies involving either conceptual or epistemic aspects. For instance, if students were asked to predict the otter population in Singapore in 5 years, they would need to understand scientific concepts such as food webs and factors affecting population growth, as well as mathematical models (e.g., linear and exponential relationships). This connection between Science and Mathematics is moderate, as it involves conceptual aspects but not epistemic aspects of Science and Mathematics (e.g., when students are not required to determine the best model).
- Finally, there can also be **weak connections** between the disciplines, defined by a dotted line. This includes using different computer software to record data in scientific experiments. The application of computer software as a tool in the problem-solving process without understanding how the software works is considered a weak connection between the disciplines of Science and Technology.

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[8] Cunningham, C., & Kelly, G. (2017). Epistemic practices of engineering for education. Science Education, 101(3), 486-505.

Characterising connections between disciplines

Connections between disciplines	*Description*
S-T	- Application of appropriate technological tools to seek causality or to investigate relationships between different variables - Application of technological tools to automate or increase accuracy of evidence collected - Application of technology to create simulations or create models to represent scientific phenomena
S-E	- Application of conceptual knowledge and models of Science to seek understanding of the functions of design - Application of scientific knowledge to search for better outcomes - Application of evidence from scientific inquiry to inform and interpret success of solutions
S-M	- Application of mathematical models to share and evaluate scientific knowledge and models - Using mathematical formulation to seek understanding of scientific phenomena - Application of mathematical tools to represent data collected during scientific investigations
T-E	- Construction of models or prototypes using technologies for a specific purpose or product - Application of engineering design to create or enhance technological solutions - Application of technological tools to evaluate and inform engineering solutions
T-M	- Application of mathematical models to create technological algorithms - Application of technological tools to create mathematical models using large data - Application of technological tools to interpret complex mathematical issues to transform them from raw to refined, simple to complex, and ill-defined to well-defined
E-M	- Application of precision from mathematical computation in the design of solutions - Application of patterns and regularity in reasoning to define and justify designs - Application of mathematical tools to collect data to search for refinement and improvement of design

Identifying strong to weak interdisciplinary connections

	Number of disciplinary connections	*“Can the problem be solved in the absence of conceptual knowledge and skills from the partner discipline?”*
Strong	A strong connection is one that has all three applications used when students are engaged in solving the problems *(see next table)*.	Not at all
Moderate	There is a moderate connection between the disciplines when the problem only requires students to engage in two of the three activities.	Partially solvable
Weak	If students only use one of the three applications in the process of problem-solving, then there is a weak connection between the disciplines.	
No connection	If there are no applications used, there is no connection between the disciplines.	Entirely solvable

B. Variations of the *Quartet* Framework

Teachers have used the *Quartet* to plan lessons that require students to solve complex, persistent, and extended problems. However, using problems as a starting point can pose uncertainties for teachers, as **students can solve the problems without learning or applying the concepts related to the intended learning outcomes**. For instance, when teaching about circuitry connections using Arduino sensors in a smart traffic light, and teachers present the students with a problem of traffic jams, students may propose solutions that can ease traffic jams without using smart traffic lights (for example, imposing heavy tolls or passing laws).

The focus on solving the problem rather than learning the disciplinary knowledge or skills could be daunting to teachers who intend to use problem-solving as a strategy for students to learn disciplinary knowledge and skills. As a result, we proposed variations to the Quartet by describing three forms of centricities: **problem-centricity, solution-centricity,** and **user-centricity**[9].

Comparison of the problem-, solution-, and user-centric STEM Quartet[10]

	Problem-Centric	Solution-Centric	User-Centric
Focus	Complex, extended, and persistent problem	An existing solution to (part of) a complex, extended, and persistent problem	The existing and potential users of the outputs of the STEM solution
Types of knowledge prioritised in 21st-Century Competencies framework	*Meta Knowledge:* Students may think creatively on different ways to collaboratively solve the problem	*Foundational Knowledge:* The solution may be well-defined and core content knowledge and cross-disciplinary knowledge are pre-identified (e.g., use of technology as a requirement)	*Humanistic Knowledge:* Development of empathy in designers can be an outcome of the process
Beneficiaries of the outcomes and outputs of engaging each model	The learners get to explore alternatives and develop a range of solutions for people to choose from	The process is systematic, and resources may be sourced and provided to systematically test the feasibility of the idea	The product is based on what users want, need, or can use. They are not forced to change their behaviour and expectations to accommodate the product, their needs are better met
Limitations of the outcomes/ outputs of engaging the various models	Wide range of solutions may be derived that may not be pragmatic unless tested and evaluated	The solution or approach may become too well-defined and limits creativity and innovation	Individual needs are diverse hence, the product may not meet the needs of a large group of beneficiaries

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9. Teo, T. W., Tan, A. -L., Ong, Y. S., & Choy, B. H. (2021). Centricities of STEM curriculum frameworks: Variations of the S-T-E-M Quartet. STEM Education, 1(3), 141-156. DOI: 10.3934/steme.2021011.
10. Ibid.

1.

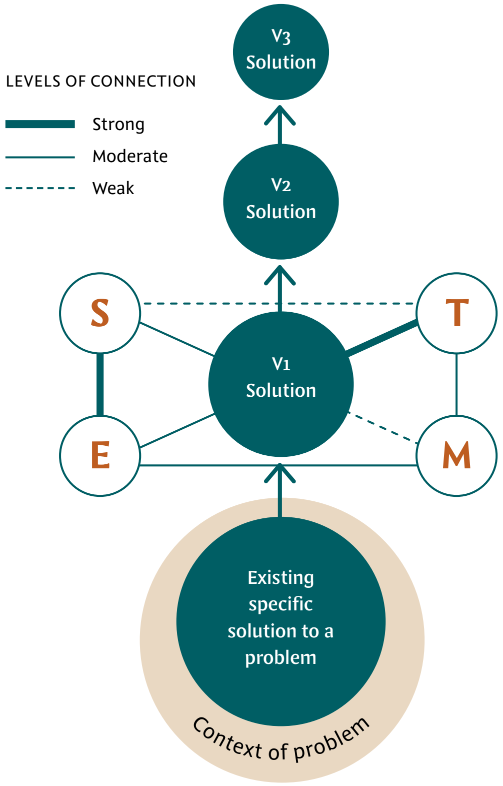
A **problem-centric STEM lesson** follows the original intention of the *Quartet* to start a lesson with a complex, persistent, and extended problem for students to solve.

2.

In a **solution-centric *Quartet***, students are first presented with different existing solutions to an identified problem. Students work on understanding the affordances of the existing solutions, their advantages, disadvantages, and limitations, and design an improved version of a solution to the problem.

Take the example of the smart traffic lights again. In a problem-centric lesson design, students will be presented with the problem of a traffic jam and asked to generate possible solutions to ease the jam. Taking a solution-centric approach, students will be presented with a smart traffic light and asked to research how smart traffic lights work, the types of problems that smart traffic lights can solve, their advantages, disadvantages, and limitations, and be tasked to design an improved version.

Design is an important aspect of deriving solutions in engineering practice and is also aligned with the intentions of 21st-century learning of meta-knowledge: namely creative thinking, critical thinking, and problem-solving.



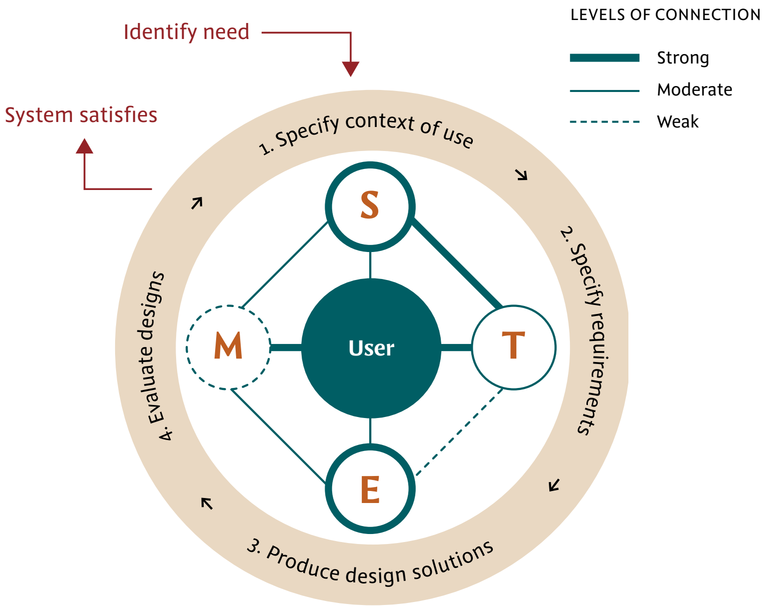
Solution-centric integrated STEM instructional framework

3.

A **user-centric *Quartet*** prioritises the needs of the user of an outcome or output. This approach focuses on developing effective and efficient strategies to address specific goals satisfactorily for the user within the context of its use.[11] A solution is only good if the user finds it useful and evaluates it positively — learners pay attention to users' evaluation of the proposed solutions.

Going back to the example of smart traffic lights and traffic jams, students could be presented with personas of different road users (e.g., the elderly, busy office workers, children, etc.) and their specific needs. Students will proceed to design solutions to ease traffic congestion for the different users.

This diagram shows the phases of a user-centric STEM approach: (1) specifying the context of use, (2) specifying the requirements or user goals, (3) creating design solutions, and (4) evaluating the designs. In user-centric STEM, we underscore the importance of humanistic knowledge.



User-centric integrated STEM instructional framework

Tip

For students who are experiencing STEM learning for the first time, we recommend starting with a solution-centric or user-centric perspective as these forms are more targeted, and learners can focus on improvements of existing solutions. For more proficient and mature learners, problem-centric STEM presents necessary challenging situations for sense-making.

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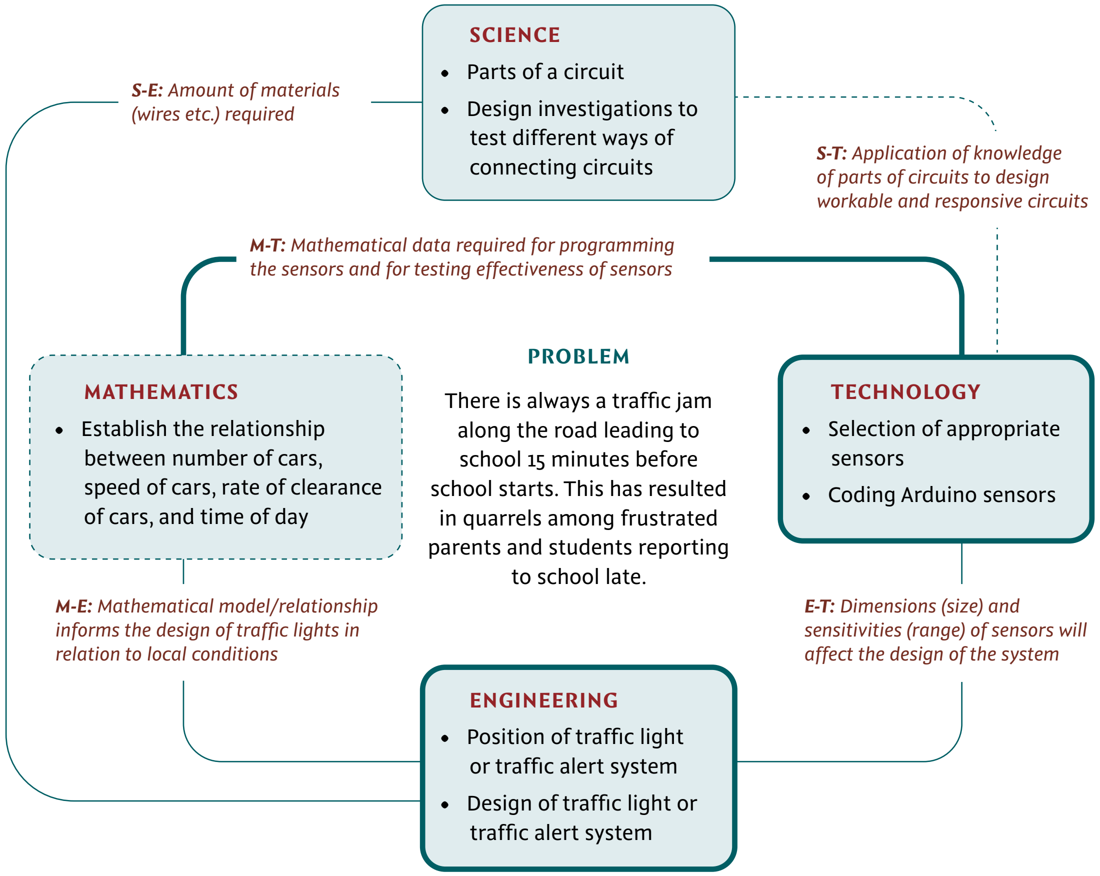
[11] Wells, J. (2016). PIRPOSAL model of integrative STEM education: Conceptual and pedagogical framework for classroom implementation. *Technology and Engineering Teacher*, 75(6), 12-19.

C. Applications of the *Quartet*

Here are examples of lessons based on the three variations of the Quartet, using the problem of traffic congestion and traffic lights.

i. The *Quartet* from a problem-centric perspective

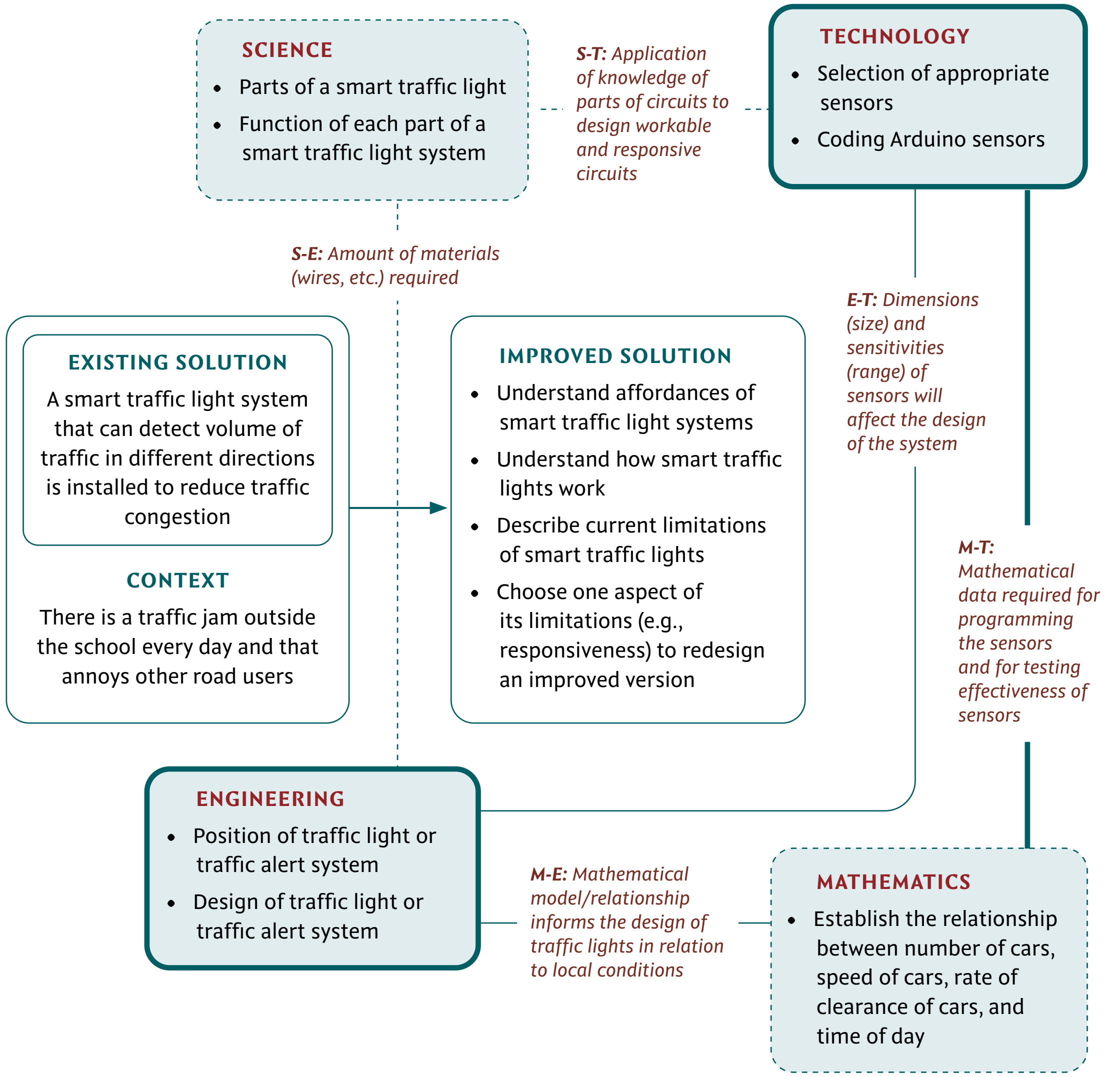
This diagram shows the intended learning outcomes and connections between disciplines when the lesson is centred around a problem.



Quartet map from a problem-centric perspective

ii. The *Quartet* from a solution-centric perspective

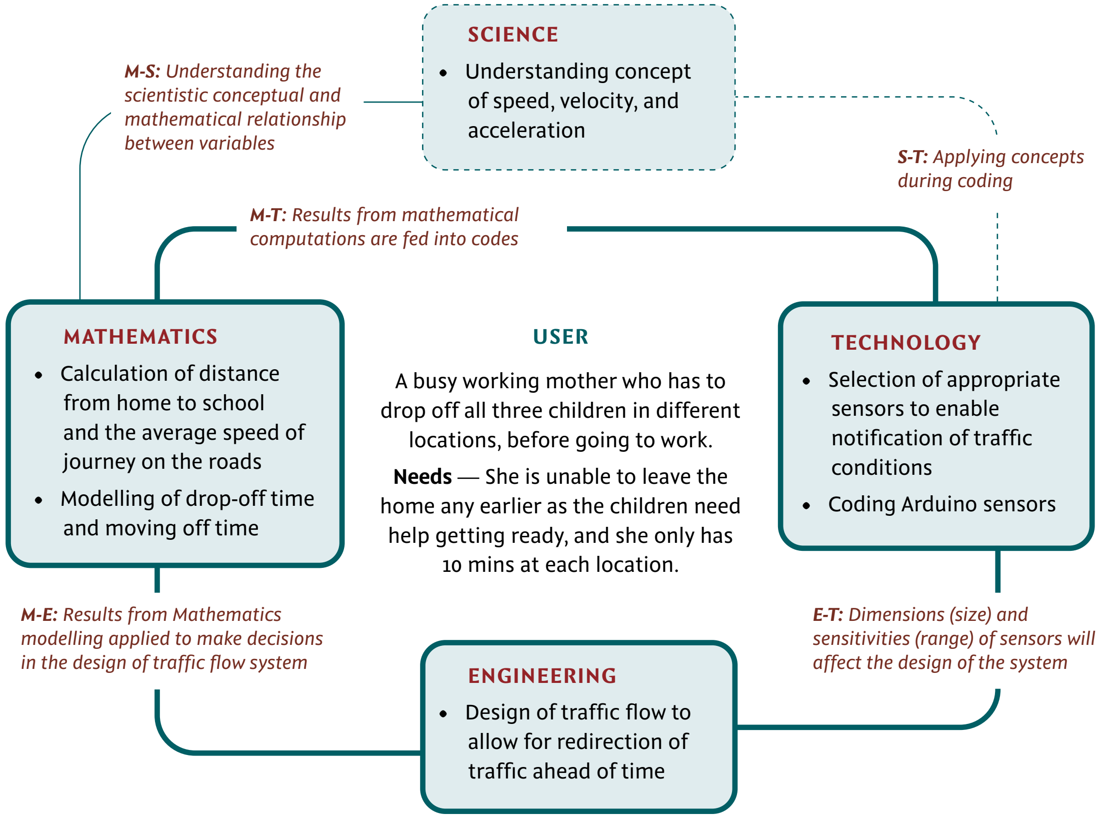
This diagram highlights the learning outcomes when the lesson starts with presenting the students with the context and the current solution (the use of a smart traffic light system). The intention shifts from solving the problem of traffic congestion to understanding the affordances, advantages, and disadvantages of the existing smart traffic light system.



Quartet map from a solution-centric perspective

iii. The *Quartet* from a user-centric perspective

This diagram illustrates a lesson that begins with the persona of a user. This lesson intends to develop a humanistic understanding of how technology (smart traffic light system), the problem (traffic congestion), and the user interact.



Quartet map from a user-centric perspective

Authors' reflections

The *Quartet* has been used by teachers and researchers since it was conceptualised in 2019. We have curated lesson ideas developed by teachers from different education systems based on each centricity and their local needs. The array of problems identified and the solutions suggested point to the value of using the *Quartet* as a planning tool to connect disciplinary ideas and problem-solving. Even as teachers accept the *Quartet*, we are continuously seeking to refine and improve the framework to ensure its currency in meeting evolving educational demands. As a living and dynamic framework, we are examining if emerging 21st-century competencies and generative AI can be considered in the *Quartet*, where appropriate. We encourage teachers to try out the *Quartet* and share their experiences with us.

Associate Professor Tan Aik-Ling & Associate Professor Teo Tang Wee

1.2

STEM Learning Framework for Fostering 21st-Century Skills in Teacher Education

Assistant Professor Dr Burin Asavapibhop, Dr Norhaniza binti Abdul Hamid, & Dr Kessara Amornvuthivorn

INSTITUTIONAL PROFILE

SEAMEO STEM-Ed

LOCATION
Regional, Thailand

TYPE OF INSTITUTION
Regional STEM specialist institution

GRADE LEVEL
K1–12

In this chapter, we learn:

- ✓ Aspects of the SEAMEO STEM Learning Framework, designed to contextualise interdisciplinary learning in STEM within Southeast Asia
- ✓ How educators may use the framework to craft teacher training programmes or classroom curricula

In the 21st century, as humanity confronts the uncertainties of the Anthropocene — an era defined by profound human impact on the Earth's systems — scientific literacy has become a critical competency. Individuals must be equipped to make informed decisions about Science-related issues such as health, climate change, and environmental sustainability, and to take meaningful action within their families, communities, and broader society.

As the regional agency dedicated to strengthening STEM education, SEAMEO STEM-Ed has designed a transformative **STEM learning framework** that promotes collaboration among cross-subject teachers.

Building upon the Three-Dimensional Learning model of the United States' Next Generation Science Standards (NGSS), this framework contextualises interdisciplinary learning in STEM education within Southeast Asia. Informed by insights from the Southeast Asian Teacher Education Programme (SEA-TEP) implementation, it integrates pedagogical anchors such as Claim-Evidence-Reasoning (CER) and student-led modelling to promote inquiry-driven and contextually-responsive, authentic learning experiences to understand and address complex social and environmental issues. Its overarching goal is to support students in acquiring 21st-century skills — including critical thinking, communication, collaboration, and creativity — while cultivating a strong sense of global citizenship.

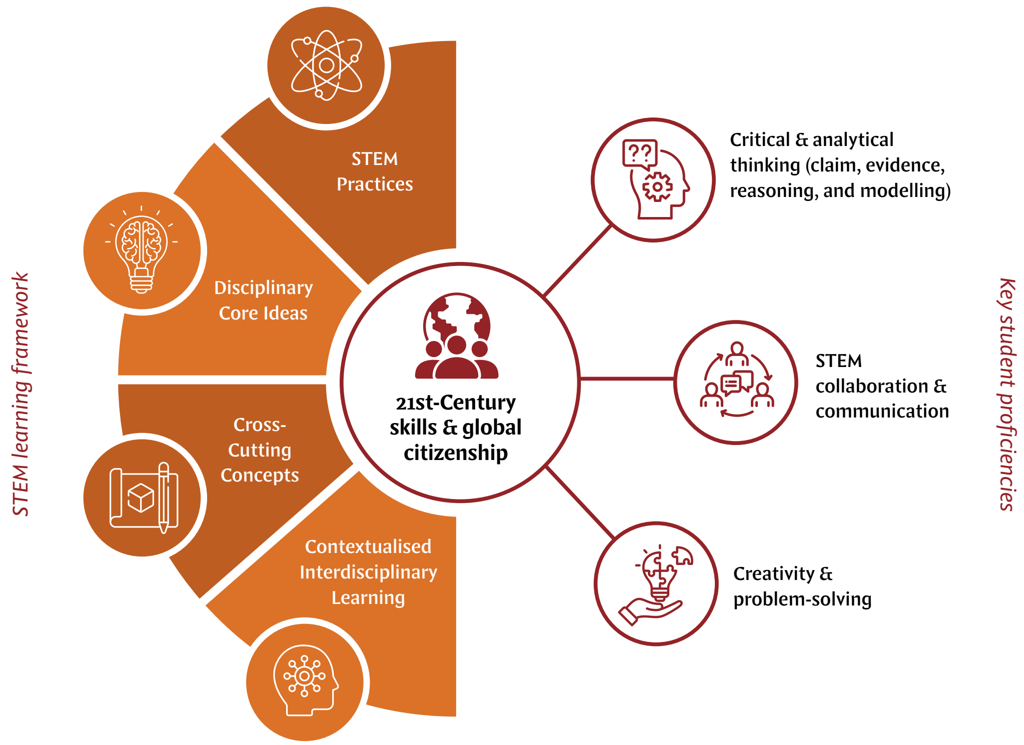
SCAN TO LEARN

More about SEAMEO STEM-Ed and their initiatives

More about the Next Generation Science Standards

More about the SEA-TEP Programme

Read more about how participants of the SEA-TEP programme implemented STEM lessons in chapters 2.4 and 3.4 of this book!



The Science, Technology, Engineering, and Mathematics (STEM) Learning Framework

Adopted from The United States' Next Generation Science Standards (NGSS) — Three-Dimensional Learning

To achieve this, teaching and learning must be structured around building strong **disciplinary core ideas (DCIs)**. We go in-depth into the DCIs in section B. Subject teachers play a crucial role in laying the foundational understanding within their respective disciplines. This is necessary before students (1) tackle contextualised interdisciplinary issues such as flooding, diabetes, and air pollution, and (2) engage in **STEM practices, integrating cross-cutting concepts (CCC)** that support their thinking, explaining, designing, and decision-making.

A. Framework dimensions

STEM practices

What students and teachers do

The following table illustrates the different processes students move through in integrated STEM learning, the skills they learn, and how teachers can construct meaningful STEM learning experiences to guide them along the way.

What students do		What teachers do
Process	**Skills learnt**	**Guidance and learning support**
1. Scientific inquiry: • Ask testable questions • Form hypotheses • Design investigations • Collect data • Analyse and evaluate data • Construct explanations • Engage in argument from evidence • Draw and communicate evidence-based conclusions	• Analytical thinking • Scientific reasoning • Evidence-based decision-making • Argumentative skills • Communication	• Guide understanding of phenomena and how evidence builds knowledge • Provide opportunities for students to carry out different kinds of investigations • Introduce techniques for displaying, analysing, and interpreting data • Have students practise using Claim, Evidence, Reasoning
2. Engineering design process: • Define real-world problems • Brainstorm solutions • Build prototypes • Test & refine designs	• Creativity • Resilience • Systems thinking • Iterative problem-solving • Collaboration • Communication	• Facilitate interdisciplinary challenges • Connect STEM to real-world and social contexts • Mobilise industry or community experts to serve as resource mentors for guiding the engineering design process • Engage students in analysing the performance and efficiency of the designed solutions.
3. Mathematical reasoning: • Apply logic, patterns, and quantitative analysis • Solve problems • Justify solutions	• Logical thinking • Critical thinking • Quantitative literacy • Abstract thinking • Precision and accuracy • Problem-solving • Contextual application of Mathematics	• Provide meaningful Mathematics contexts • Scaffold problem-solving with multiple representations (e.g., graphs, models, equations) • Encourage students to justify solutions and critique reasoning • Highlight the role of patterns and structures in generating solutions • Integrate mathematical reasoning into interdisciplinary STEM contexts
4. Computational thinking: • Breakdown complex problems • Identify patterns • Create algorithms • Code and model systems	• Algorithmic thinking • Digital literacy • Abstraction and decomposition	• Fostering problem-solving mindsets • Support programming, modelling, and automation activities by integrating technology to engage students in real-world practices of programmers
5. Use of technology: • Research, collaborate, simulate, and communicate using digital tools • Collect and critique data	• Technological fluency • Data analysis • Collaboration • Communication	• Model responsible and effective use of technology • Encourage the exploration of computer applications for data analysis and evaluation • Support digital learning environments

Read how teachers have used these two pedagogies in their lessons, in chapters 2.4 and 3.4 of the book!

(top) Students engaging in scientific inquiry to measure water quality in a local watershed

(right) Students applying mathematical reasoning to analyse coastal erosion and develop a prototype for the solution

Pedagogical anchors for deep learning

To deepen STEM practices, educators anchor instruction in powerful pedagogical strategies and learn about two examples in the table below.

Pedagogical anchors	
Claim, Evidence, Reasoning (CER)	**Student-led modelling**
• Provides a framework for scientific argumentation • Helps students articulate conclusions supported by data, and explain their reasoning using scientific principles • Strengthens critical thinking and communication	• Constructs physical, digital, or conceptual models to represent systems and explore “what if” scenarios • Allows visualisation of complex interactions and testing of variables • Promotes ownership of learning • Helps students refine their understanding of the content knowledge

Students present their claim using evidence with support from scientific reasoning

Disciplinary core ideas

What foundational concepts from relevant disciplines do students learn and apply?

Disciplinary core ideas (DCIs) are the essential building blocks of scientific understanding evolving in depth and complexity as students advance through grade levels. They explain natural and technological phenomena and serve as the foundation for learning within and across scientific disciplines. Mastery of DCIs is vital for engaging meaningfully with STEM practices and integration of cross-cutting concepts to solve real-world problems.

Core domains of DCIs

Physical Science

Life Science

Earth and Space Science

Engineering, technology, and applications of Science

Mathematics as an essential tool

Unique to this framework is the inclusion of Mathematics as an essential tool. As a critical enabler of scientific inquiry, engineering design, and technological innovation, Mathematics allows educators to intentionally develop students' mathematical thinking alongside other STEM competencies.

Key mathematical domains relevant to interdisciplinary STEM learning are:

- **Arithmetic & Algebra** — Fluency in operations, expressions, and equations help students model relationships and solve problems using symbolic reasoning
- **Geometry** — Builds spatial reasoning and measurement skills for design and analysis
- **Calculus** — Introduces rates of change and limits to understand dynamic systems
- **Number Theory** — Explores properties of integers, including primes and divisibility, supports logical reasoning, and has applications in cryptography and computing
- **Probability & Statistics** — Teaches students to analyse data, measure variability, and assess uncertainty for interpreting experimental data and making evidence-based decisions

By developing proficiency in these mathematical domains, students can interpret data, construct models, and generate solutions that are grounded in logic and precision. Mathematics hence becomes not just a tool, but a language that enables learners to engage deeply with STEM content and contribute meaningfully to real-world problem-solving.

Integrating Social Science

With the growing focus on environmental education, this framework encourages the integration of Social Science with STEM. Topics such as sustainability, ethics, and policy enable students to gain a deeper understanding of how scientific advancements shape — and are shaped by — human affairs. This approach supports a more comprehensive view of global challenges and highlights the importance of understanding the social dimensions of Science and technology.

Cross-cutting concepts

How disciplines interconnect

Cross-cutting concepts (CCCs) are cognitive tools that help connect knowledge across disciplines, fostering interdisciplinary literacy between STEM and non-STEM subjects. By embedding CCCs into teacher education, the SEA-TEP programme equipped educators and learners to think flexibly, reason across boundaries, and approach STEM as an interconnected framework for solving global challenges.

There are six key CCCs in the framework:

Patterns, similarity, and diversity

Cause and effect

Structure and function

Scale, proportion, and quantity

Systems and system models

Stability and change

In the SEA-TEP teacher professional development programme, six CCCs were implemented to develop students' interdisciplinary literacy.

Cross-cutting concepts in the SEA-TEP framework

Cross-cutting concept	Key focus	SEA-TEP strategy	Example tool
Patterns, similarity, and diversity	Classification, trend analysis, and prediction	Comparative analysis and visual data interpretation to compare and evaluate patterns across biological, physical, social, and cultural contexts	Charts/graphs
Cause and effect	Underlying mechanisms, causal reasoning (i.e., understanding causal relationships)	Claim–Evidence–Reasoning (CER) framework to scaffold students' explanations to promote scientific reasoning and argumentation across disciplines	CER templates
Structure and function	Design insights and anatomical reasoning	Modelling tasks and design analysis to investigate how structural features (i.e., physical, mathematical, or organisational) affect outcomes	Hands-on models
Scale, proportion, and quantity	Magnitude and proportional reasoning	SageModeler for mathematical modelling to simulate systems and reinforce quantitative reasoning	SageModeler
Systems and system models	Component relationships and feedback	System diagrams and simulation activities to model feedback loops and predict behaviour and promote systems thinking	SageModeler
Stability and change	Dynamics, resilience, and understanding thresholds	Temporal analysis and scenario modelling to explore how systems evolve and what drives resilience or transformation	SageModeler

Contextualised interdisciplinary learning

Another essential dimension of the developed STEM Learning Framework is **contextualised interdisciplinary learning**, which seeks to bridge STEM disciplines through pedagogies rooted in local relevance, cultural responsiveness, and sustainability. This approach aligns with global educational imperatives such as the United Nations Sustainable Development Goals (UNSDGs) and Global Citizenship Education (GCED), as well as regional frameworks including the SEAMEO Strategic Plan. Through interdisciplinary teaching strategies, students are guided to apply scientific and technological knowledge to real-world challenges in their communities, thereby enhancing learner engagement and fostering the development of 21st-century skills such as analytical thinking, collaborative problem-solving, and effective communication.[1]

Key thematic areas for integration include environmental stewardship and resilience, sustainability and human impact, and disaster risk reduction — all of which are increasingly relevant amid the climate crisis and regional vulnerabilities in Asia.

A crucial aspect of implementing contextualised interdisciplinary learning effectively is the localisation of global frameworks to Southeast Asian contexts, ensuring that international educational goals resonate with the unique cultural, environmental, and socio-economic realities of the region. By embedding these global educational frameworks, such as the UNSDGs into STEM curricula and community-based learning experiences, educators can foster meaningful engagement with local challenges. Students are hence encouraged to not only acquire content knowledge but also to examine the ethical, cultural, and societal implications of STEM applications[2], to become informed, globally competent, and socially responsible learners who can make meaningful contributions to sustainable developments as active agents of change[3].

SCAN TO LEARN
More about the SEAMEO Strategic Plan 2021–2023

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B. Key student proficiencies

The central aim of the STEM Learning Framework is to cultivate a set of core student proficiencies essential for navigating complex real-world challenges.

Proficiency	How it's cultivated
Critical & analytical thinking	Through inquiry-based learning, data interpretation using the CER framework, and scientific modelling[4]
Communication	Through CER-based discussions, oral and visual presentations, and digital storytelling to articulate scientific understanding
Collaboration & teamwork	Through group projects focused on real-world problem-solving using integrated STEM practices, fostering shared responsibility and cooperation
Creativity & problem-solving	Through engaging in design thinking processes, engineering challenges, and contextual scenarios that require creative, innovative, and practical solutions

C. Teacher education applications

To effectively implement contextualised interdisciplinary STEM education, teacher education must go beyond conventional training and include structured approaches that integrate pedagogical innovations with local relevance. Teacher educators can use the framework as a guide for training design.

Application area	Description
Curriculum design	Integrate STEM disciplines through core ideas grounded in interdisciplinary learning
Facilitator training	Focus on CER and modelling pedagogy to enhance STEM instruction
Context-specific resource development	Develop teaching materials that reflect the local culture, environment, and needs
STEM-aligned assessment	Utilise assessment tools that align with STEM practices and cross-cutting concepts
Reflective practice	Employ community-based case studies for reflective teaching improvement

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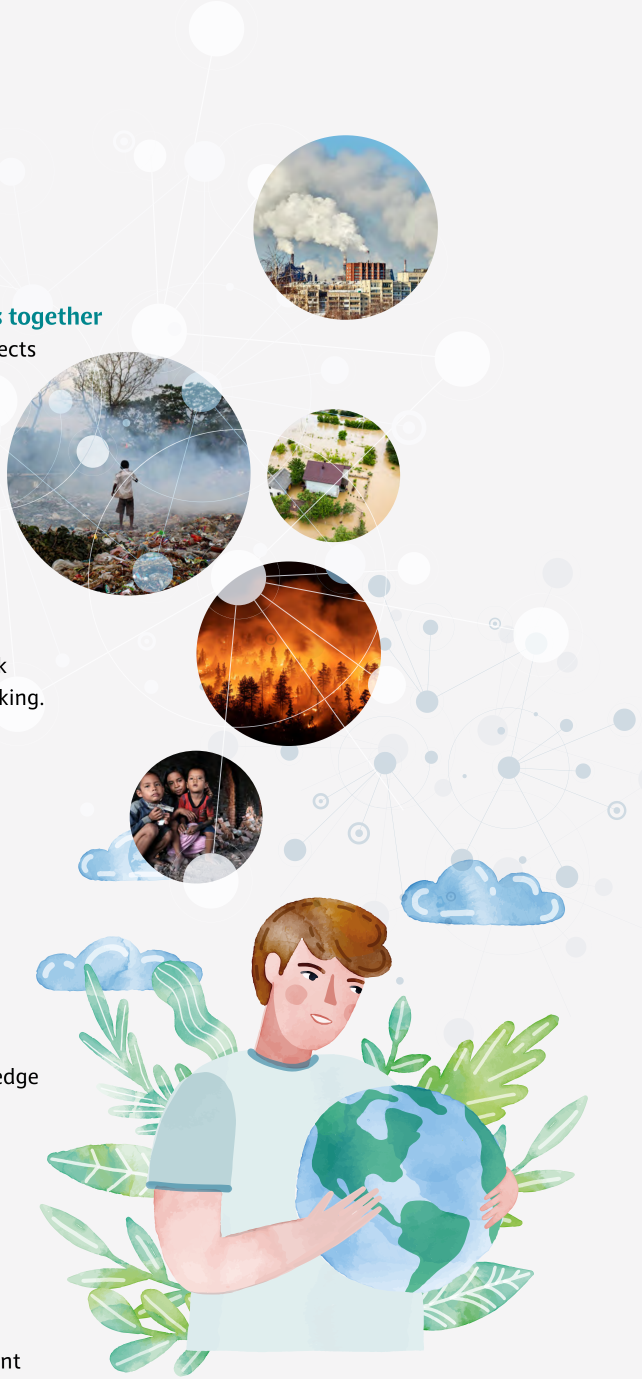
[4] Gamage, K. A. A., Ekanayake, S. Y., & Dehideniya, S. C. P. (2022). Embedding Sustainability in Learning and Teaching: Lessons Learned and Moving Forward-Approaches in STEM Higher Education Programmes. *Education Sciences*, 12(3). https://doi.org/10.3390/educsci12030225

10 tips for implementing the SEAMEO STEM Learning Framework



1. **Start with a contextualised problem**
Anchor STEM lessons in a local issue
(e.g., flooding, pollution, agriculture, health).

2. **Integrate Social Science and ethics**
Highlight the social, ethical, and policy dimensions
of STEM (e.g., climate action, sustainability, equity).

3. **Empower students to solve real-world problems together**
Foster teamwork and civic engagement through projects
that address authentic community challenges.

4. **Balance disciplinary core ideas with interdisciplinary learning**
For example, ensure that students grasp
foundational scientific and mathematical concepts
before moving on to interdisciplinary tasks.

5. **Leverage pedagogical anchors**
Apply the Claim-Evidence-Reasoning (CER) framework
regularly to promote argumentation and critical thinking.

6. **Team up across subjects to unlock project time**
Organise interdisciplinary lessons to create space
for meaningful, hands-on STEM exploration.

7. **Embed cross-cutting concepts explicitly**
Make patterns, cause-effect, structure-function,
and systems thinking visible in lesson discussions.

8. **Connect with experts to enrich learning**
Empower teachers to act as facilitators by leveraging
external expertise, to share discipline-specific knowledge
and skills beyond the teachers' scope, boosting
school-to-industry collaborative support.

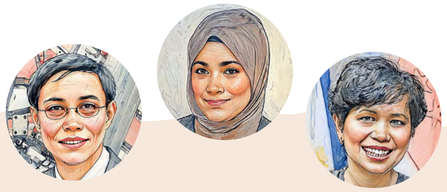
9. **Develop customised and localised resources**
Adapt teaching materials to reflect the local culture,
environment, and needs.

10. **Assess beyond content knowledge**
Move beyond simple factual recall by using assessment
tools aligned with STEM practices and cross-cutting
concepts.

Conclusion

Advancing holistic STEM education for a sustainable future

The SEAMEO STEM Learning Framework offers a comprehensive and transformative approach to education by weaving four essential dimensions: STEM practices, disciplinary core ideas, cross-cutting concepts, and contextualised interdisciplinary learning. The framework ensures that STEM education is both globally benchmarked and locally grounded. It fosters inclusive, equitable, and impactful learning experiences that cultivate Southeast Asian learners who are ethical, innovative, and socially responsible contributors to sustainable practices in their communities and beyond.



Authors’ reflections

The framework serves as a valuable lens for highlighting interdisciplinary connections and real-world relevance contextualised to the Southeast Asian region. It illuminates how sustainability issues can be addressed through integrated STEM learning, cultivating both technical competencies and civic responsibility. The selection of exemplary practices was guided by the framework’s emphasis on project-based learning, collaboration, and community engagement. For successful implementation, it is essential that teachers work across disciplines to overcome time constraints and leverage their collective expertise. This shift requires educators to move from traditional instruction to facilitation — guiding students as they apply knowledge to authentic challenges. By mobilising industry and community experts, teachers enrich the learning process with real-world insights and feedback, enhancing the relevance and impact of student solutions. Engaging students in community-based issues not only deepens their understanding of STEM concepts but also raises awareness of social problems, reinforcing the role of education in driving sustainable development.

Assistant Professor Dr Burin Asavapibhop, Dr Norhaniza binti Abdul Hamid, & Dr Kessara Amornvuthivorn

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1.3

The EDICRA Framework for Early Childhood and Primary STEM Education

Mr Tanit Minwong, Ms Jidlada Manora, Ms Nicharee Pramualsab,
Ms Ratchatha Netthip, & Ms Sooprawee Wuttisawat

INSTITUTIONAL PROFILE

Starfish School

LOCATION
Chiang Mai, Thailand

TYPE OF INSTITUTION
Private early childhood and primary school

GRADE LEVEL
Kindergarten to Primary 6

In this chapter, we learn:

- ✓ Elements of the EDICRA framework as an inquiry-based framework for STEM education
- ✓ How the framework is applied to STEM learning in an early childhood and primary education capacity
- ✓ How to encourage student-centric learning

Starfish School operates under the guidance of the Starfish Education Foundation, with a mission to promote equitable access to quality education tailored to each learner's potential in the 21st century. With a strong belief that education is a key driver for sustainable development, the school is committed to offering meaningful learning opportunities through diverse and innovative approaches.

The EDICRA (Explore, Define, Investigate, Create, Reflect, Act) framework was developed for early childhood and primary school learners at Starfish school, with the aims of:

- Developing students’ ownership of learning, problem-solving abilities, and emotional intelligence
- Cultivating innovation, teamwork, and lifelong learning habits
- Strengthening connections between school, family, and community

This framework specifically focuses on **Problem-Based Learning** and **Project-Based Learning** instructional methods that encourage students to actively explore real-world challenges and develop solutions through hands-on, collaborative learning experiences.

Alongside this core approach, Starfish School integrates other innovations such as makerspace activities that promote student agency and 3R innovation — ensuring every child develops core competencies in reading, writing, and arithmetic. These foundational skills not only prepare students for academic success but also equip them for real-world challenges.

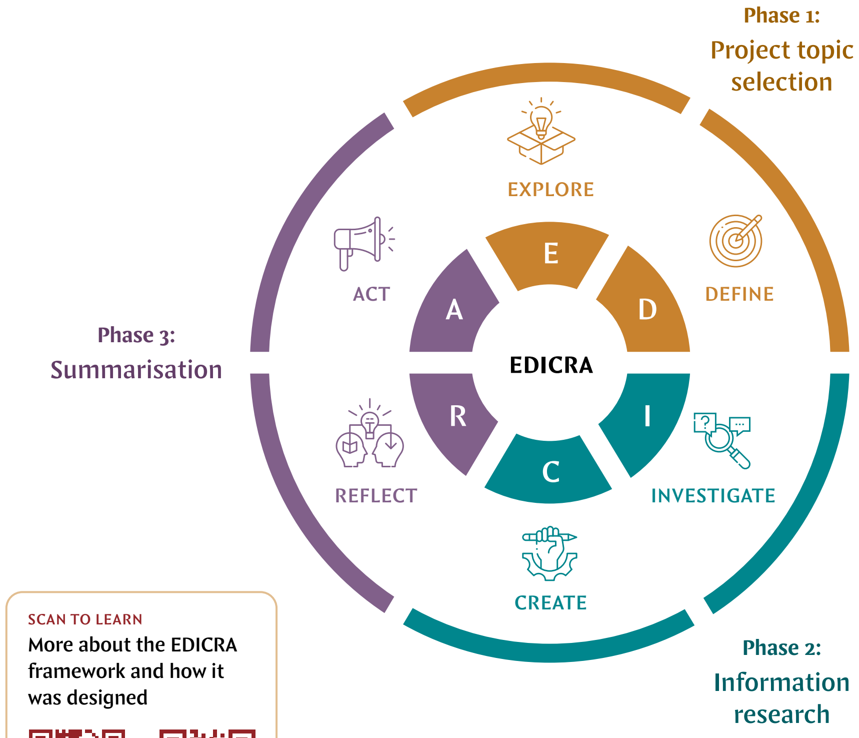
SCAN TO LEARN
More about Starfish School and their curriculum

This framework is applicable to:

- Schools serving marginalised or ethnically diverse communities
- Educators seeking to implement student-centred, real-world learning approaches
- Learning environments requiring integration of STEM, literacy, and 21st-century skills

The EDICRA framework as an inquiry-based approach to STEM learning

Inquiry-based learning in STEM is a student-focused approach that uses open-ended problems or challenges. Thus, each students' lived experiences, prior knowledge, and resultant actions present a unique base and approach for the project or problem at hand. The EDICRA framework uses inquiry-based learning methods (such as Project-Based Learning and Problem-Based learning) as a central teaching approach, so that students are empowered to engage with personally meaningful topics, real-life issues, and authentic community problems. Aligning students' learning experiences with projects or problems of their interest cultivates empathy and boosts intrinsic motivation, providing opportunities for students to connect theoretical knowledge to real-world applications. The EDICRA framework leverages inquiry-based learning to foster a deeper understanding of content through collaboration, critical thinking, and self-directed learning — STEM skills that are increasingly recognised as crucial in helping youth navigate life and contribute positively to their communities.



The EDICRA Learning Framework

By Dr Nanthaporn Prae Seributra,
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SCAN TO LEARN

More about the EDICRA framework and how it was designed

in English *in Thai*

Starfish School in Chiang Mai was a Top 3 Finalist for the 2024 World's Best School Prize for Innovation

Teaching for diversity and student ownership

At Starfish School, diversity is at the heart of the learning community. Approximately 50% of students are Thai, while the other half represent eight different ethnic groups, each bringing their own language and cultural heritage into the classroom. This presents a unique challenge in delivering inclusive education that meets the needs of all learners.

To work with diverse students, teachers can use Active Learning techniques like collaborative learning and peer tutoring. These methods encourage students with different abilities and backgrounds to work together, share knowledge, and solve problems. This interaction helps students take responsibility for their own learning while also supporting their peers. When students with different experiences and abilities collaborate, they can brainstorm, share ideas, and use their varied skills to complete activities. This exchange of ideas and reflection on personal experiences promotes effective teamwork and helps students learn from one another's unique perspectives.

This is achieved through a multi-faceted approach where teachers act as facilitators, guiding students in hands-on activities that encourage them to construct their own knowledge. It is essential to create a supportive and safe classroom environment that fosters collaboration over competition, allowing students the confidence to express themselves. Furthermore, teachers should provide clear guidance, offer choices in how students learn and present their work, and encourage self-reflection to help students grow and take responsibility for their own development. Positive reinforcement, such as stars or points, also helps to build a growth mindset and motivate students to engage with new ideas.

A. Using the framework for early childhood STEM education

For the kindergarten level, the framework adopts a 3-phase **Project-Based Learning** cycle.

Phase 1: Project topic selection

Exploring surroundings, discussing interests, and sharing experiences

- Students are guided to explore their school surroundings or watch videos and movies
- Teachers and students discuss topics and activities that the students want to learn more about
- Students share their experiences and what they would like to learn with their friends

Phase 2: Information research

Brainstorming, integrating multiple subjects, and active learning through real-world experiences

- Students and teachers brainstorm together and share ideas for finding information on a chosen topic
- Students have the chance to express their opinions
- Teachers integrate various subjects into the lesson
- Students learn through active learning with hands-on experiences, such as studying real objects and visiting relevant sites or physical spaces

Phase 3: Summarisation

Mind mapping, reviewing activities, preparing exhibitions, and presenting outcomes

- Teachers and students collaborate to summarise activities from the start of gathering information in Phase 2 and create a mind map
- They discuss and review the activities together in preparation for the class project exhibition
- Students rehearse their presentations for the class project display
- Parents and guests are invited to watch students present their findings on the class exhibition day

See how the framework is implemented in an actual lesson for early childhood education in chapter 2.1!

Tip

Integrating multiple subjects at the kindergarten level can be done at the stages of Inquiry and Data Collection, where activities connect topics learnt.

For example, in Science, students may explore school buildings and teachers' residences or observe their surroundings. In Mathematics, they may count the number of trees in their school garden, or the number of teacher residences. In Thai language class, they may practise learning and writing the names of different types of houses or compose rhymes on houses.

B. Using the framework for primary school STEM education

For the primary level, the framework adopts a six-phase **Problem-Based Learning** cycle. Through this process, students identify real-life problems, research solutions, develop innovations, review their work, and implement the results within their communities.

Phase 1: Explore

- Students identify topics they are interested in or problems they want to solve
- These can be issues in their daily life, concerns in their own communities and homes, or national concerns

Phase 2: Define

- Students are split into groups and guided to clearly state the problem or topic to explore
- Groups do not need to choose the same topic

Phase 3: Investigate

- Students research and build a body of knowledge related to their chosen topic

Tip

By assigning students different roles based on their abilities and interests, this can ensure that everyone has clear duties and responsibilities while maintaining a balance in group work. Roles can then be rotated to support the holistic development of students' skills.

Phase 4: Create

- Students develop an invention or piece of work that aligns with the knowledge gained from the research and collaborate with peers to actualise their ideas

Phase 5: Reflect

- Students review and exchange knowledge about their projects with their classmates. During this phase, the teacher acts as a facilitator, using targeted probing questions to encourage deeper and more comprehensive reflection

Phase 6: Act

- Groups implement their invention or solution in their community to create positive change

See how the framework is implemented in an actual lesson for the primary level in chapter 4.4!

Topic: Understanding bananas (Nam Wa variety)

Early childhood level
Three phases of activities

Phase 1:
Choosing the project topic

- ***Explore:*** Children observe banana plants — their colours, shapes, and taste of the fruit
- ***Define:*** They ask themselves, “What fun and meaningful activities can we do with bananas?”
- ***Goal:*** To develop observation skills and the ability to ask questions

Phase 2:
Information inquiry

- ***Investigate:*** Learn where bananas come from, through pictures, videos, or field visits to local farms
- ***Create:*** Engage in simple crafts, such as folding banana leaves into shapes or making toys from banana sheaths
- ***Goal:*** To encourage creativity, experimentation, and exploration

Phase 3:
Project conclusion

- ***Reflect:*** Share with friends or family what they learned about bananas
- ***Act:*** Present their creations to classmates or hold a small exhibition
- ***Goal:*** To foster communication, reflection, and collaboration skills

From 3 to 6 phases: Moving from early childhood to primary school

The key differences in the EDICRA framework when moving from the three phases in kindergarten to the six phases in primary school lie in the **role of the teacher** and the **process of topic selection**.

At the kindergarten level, project themes are largely driven by children’s interests, with teachers playing a more significant role in stimulating curiosity. This is achieved through multiple approaches, such as exploring the surrounding environment, watching videos, visiting the library, and engaging in creative follow-up activities like drawing, painting, clay modelling, or collage work. Teachers then consolidate children’s expressed interests, and the class votes to select one central theme to work on collectively.

In contrast, at the primary level, learning is problem-based. Students themselves explore and form groups around problems of interest. Each class typically works on four to seven different problem topics, and students with unique interests not shared by their peers may even undertake individual projects. The EDICRA process is implemented sequentially through all six stages at the primary level. In kindergarten, however, the stages are clustered: Explore and Define (E–D) occur during topic selection, Investigate and Create (I–C) during inquiry and active exploration, and Reflect and Act (R–A) during project consolidation and presentation.

The EDICRA framework enables students to engage with STEM in a systematic manner — progressing from exploration, design, implementation, creation, reflection, to application. For early childhood learners, this process fosters observation skills and creative thinking, while at the primary level, it advances towards scientific and technological problem-solving.

Here is an example of how the same topic is taught at an early childhood level and primary level, using the two variations of the framework.

Topic: Understanding bananas (Nam Wa variety)

Primary level
Six phases of activities

Phase 1: Explore *(Problem Exploration):*
Study the life cycle of banana plants and challenges faced by farmers, such as harvesting or preservation

Phase 2: Define *(Problem Definition):*
Formulate project questions, e.g., “How can we add value to Nam Wa bananas?”

Phase 3: Investigate *(Problem Investigation):*
Research banana preservation methods, banana-based products, and the required resources

Phase 4: Create *(Product Creation):*
Design and develop a STEM-based solution, such as a solar-powered banana dryer

Phase 5: Reflect *(Learning Reflection):*
Analyse project outcomes, and identify successes and areas for improvement

Phase 6: Act *(Making a Difference):*
Apply the solution in schools or communities to evoke positive change, such as reduce waste, increase product value, and more

Other topics that can be introduced at the kindergarten level and later expanded upon include: rice, local flowers, water, insects, and common animals.

These are familiar topics to children, have a direct relation to nutrition or natural sciences, and can be easily expanded upon in upper grades.

C. Applications of the EDICRA framework

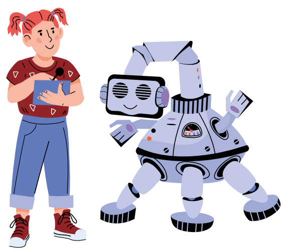
Educators can use the framework to guide them in:

Curriculum integration

Core subjects (Thai, Mathematics, English, Science) are embedded into Project-Based Learning/ Problem-Based Learning activities, ensuring academic relevance while fostering critical thinking and creativity.

Community connection

Topics and problems are drawn from students’ immediate environment, encouraging local engagement and culturally responsive education.



Innovation development

Students design tangible solutions (e.g., eco-friendly cleaning products, automated chicken feeders, rice straw conversion into useful products such as charcoal or pots) that benefit their communities.

A guide to student-centred learning

1.

Start from students' context

Choose topics relevant to their daily lives, culture, and environment

2.

Integrate multiple subjects naturally

Connect literacy, numeracy, Science, and Arts into project/problem tasks

3.

Facilitate, don't dictate

Guide students with questions, challenges, and resources while allowing them to make decisions

4.

Empower students to take ownership of their learning

Students plan their learning on problems or areas of interest

5.

Encourage reflection

Provide regular opportunities for students to evaluate their learning process and outcomes

6.

Promote safe and responsible use of technology

Guide students to build digital competence and develop media literacy

7.

Connect to the community

Involve local experts, families, and real-world audiences to make learning more authentic

8.

Document and share

Record processes and products for future cohorts to learn from and improve upon

Success indicators include:

- Students create and implement practical solutions addressing local challenges, such as organic cleaners, pest traps, and water removal carts
- Teachers report improved critical thinking, collaboration, and confidence among students
- Families and communities note increased student responsibility and real-world application of knowledge

Conclusion

The EDICRA Project-Based Learning (Kindergarten) and Problem-Based Learning (Primary) framework at Starfish School demonstrates that student-centred, real-world learning can thrive even in culturally and linguistically diverse, marginalised communities. By integrating core subjects into hands-on, interdisciplinary projects and problem-solving tasks, this approach cultivates ownership of learning, critical thinking, creativity, and community engagement.

This pedagogy not only addresses academic growth but also nurtures social-emotional skills, innovation, and sustainable problem-solving habits. The real-life application of student projects — such as eco-friendly cleaning products, pest traps, and community tools — has had tangible positive impacts on both learners and their communities.

Authors' reflections

As teachers, we have noted the importance of involving students in the regular practice of reflection. Helping our students interpret what they have learnt and make explicit connections to their experiences is one method we have employed to involve students in reflecting on their own learning.

Reflection can also be used to prompt students to consider a wider perspective, such as how their families, society, and communities could benefit from the learning and problem-solving that they have engaged in. At Starfish School, we believe that by actively instilling the practice of reflection, this will help students develop a responsible mindset and grow to become good citizens with a conscience for helping others.

Mr Tanit Minwong, Ms Jidlada Manora, Ms Nicharee Pramualsab, Ms Ratchatha Netthip, & Ms Sooprawee Wuttisawat

1.4

Reimagining STEM Lesson Design the Hackathon Way

Dr Melissa Neo

INSTITUTIONAL PROFILE

meriSTEM@NIE, InsPIRE-Teaching Learning and Pedagogy, Nanyang Technological University

LOCATION
Singapore

TYPE OF INSTITUTION
Teacher education and training

GRADE LEVEL
Pre-service teachers

In this chapter, we learn:

- ✓ About hackathons, some formats of hackathons, and their affordances
- ✓ Key steps in designing a STEM hackathon
- ✓ Challenges and tips to consider when planning and implementing a STEM hackathon

Originally designed as highly specialised events for the software and technology industry, hackathons are an effective way of fostering creativity and innovation for students. They learn important STEM skills through experimentation with digital technologies for rapid open-source development, product innovation, and more. Having developed from its early days as impromptu informal coding sessions, to corporate competition-driven events where various participants compete for funding or prize money, hackathons have evolved to encompass a broader pedagogical and professional framework and are increasingly being embraced as a powerful platform adopted across many sectors. From the healthcare industry to government, finance, and education sectors, the **hackathon phenomenon** has become an attractive tool to tackle complex challenges in an accelerated environment to catalyse innovation, iterative design, and technical/skill acquisition. It is characterised by intense, time-bound problem-solving, collaboration, and prototyping, and fosters interdisciplinarity at both the level of content knowledge and teamwork[1].

In this chapter, we explore the fundamental steps for designing a STEM education-focused hackathon.

Read more about how a STEM hackathon can be implemented in chapter 3.5 of the book!

What is a hackathon?

A hackathon is a time-bound, challenge- or problem-focused event where participants develop innovative functional prototypes or solutions. Stemming from the combination of **hack** and **marathon**, **hack** refers to the act of exploratory problem-solving (through programming), while **marathon** refers to a period of intense and sustained effort (typically 24 to 72 hours). Although participation in hackathons could traditionally be undertaken by individuals or groups, they are increasingly being utilised as a team-based model to develop and enhance interdisciplinarity.

A hackathon can take on various formats and can be designed to accommodate approaches tailored to specific goals, audiences and resources. For example, a classic hackathon brings together programmers, developers, and technology enthusiasts to create an innovative and functional prototype or solve a specific problem within 24 to 48 hours. In comparison, a hackathon can be conducted as a single or half-day event, or as a longer extended project, catering to the needs of different schools and student readiness, with different benefits and outcomes. The next table briefly compares two hackathon formats with an extended project from the perspective of creating STEM educational experiences.

Comparing two hackathon types and an extended project type

	Mini-hackathon	Classic hackathon	Extended project
Duration	Half day to 1 day	24 to 48 hours	Weeks to months (e.g., term or semester)
Scope	Well-defined theme/ problem	Single (focused)-problem	Complex and broad problem with multiple components
Primary Goal	• Teach or build on specific concepts or skills • Demonstrate proof-of-concept (or low fidelity) prototype (solution may not be tested)	• Rapid prototyping • Demonstrate solution feasibility (solution is functional and not fully polished)	• Develop a well-researched solution • Solution should be tested and well/more polished
Core Affordances	• Low time commitment (multiple hackathons of differing themes can be held over time) • Intense collaboration • Self-directed microlearning modules/ workshops to learn specific skills	• High-energy environment (rapid ideation, decision-making, and prototyping) • Intense collaboration	• Comprehensive review and understanding of the relevant content knowledge • Data collection and analyses • More opportunities for testing, iterative prototype design, and feedback for a more polished final product/solution • Involve external STEM professionals as mentors (fosters opportunities for networking and potential internships)

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1. Briscoe, G. (2014). *Digital innovation: The hackathon phenomenon.* http://qmro.qmul.ac.uk/xmlui/handle/123456789/11418

Teams brainstorming at the SingHealth Hackathon 2023

A. Hackathons as a tool in STEM

In Singapore, STEM hackathons have been featured as an engagement tool for progressing towards the country's **Smart Nation** goals, connecting various organisations, industries, and citizens via a single platform. One example is the SingHealth Hackathon in 2023[2]. Conducted as a collaborative partnership between SingHealth Graduate Medical Education, its Education & Research Subcommittee, and innovation accelerator Padang & Co, this 2-day event convened a diverse cohort of participants. Healthcare practitioners from various departments, hospitals, and polytechnic students gathered to ideate scalable solutions for healthcare waste. Aligning with Singapore's national "Towards Zero Waste" mandate by 2030, the event demonstrated how the unique constraints of a hackathon could (1) facilitate and augment a team-centric approach in ways that a standard project-based or problem-based lesson cannot replicate, and (2) encourage cross-sectoral innovation.

In the education sector, STEM-based hackathons are similarly being adopted as a viable alternative for STEM learning and student development[3]. NIE and meriSTEM@NIE initiatives[4] — including the AI-Coding Hackathon (for undergraduate and postgraduate students, teachers and researchers); Empowering STEM Education Workshop (for local pre-service and in-service teachers); and EPIC STEM Hackathon (for grade 9 students) — leverage hackathons to stimulate interest in programming and cultivate future-ready competencies for the digital economy across all academic levels.

Unlike conventional learning experiences, STEM hackathons offer a unique space for dynamic problem-solving and present several logistical and pedagogical affordances, some of which are unpacked below.

1.
Innovative problem-solving: The hackathon provides a dedicated space for creative risk-taking as students rapidly shift from understanding the problem/challenge to solution ideation and prototyping. The limited timeframe incentivises students to pursue more unconventional ideas without focusing too much on achieving the correct solution.

2.
Management of time and resource needs: A classic or mini-hackathon serves as a logistical "pressure cooker", affording schools a compacted 24- to 48-hour window for an immersive STEM learning experience. This bypasses traditional scheduling conflicts such as long-term resource allocation and displacement of subject-specific curriculum time. In addition, the choice of hackathon format offers further flexibility, where a classic hackathon provides deeper immersion and a mini-hackathon offers a lower-barrier alternative for schools operating within more restrictive schedules or budgets.

3.
Student autonomy and agency: In a hackathon, a teacher takes on the role of a facilitator or guide. Students are the primary decision-makers as they define their project scope, ideate, and iteratively test and tweak their prototype/solutions. Other examples of student agency include how groups manage resources such as time (e.g., through distribution of the work required, inclusion of adequate iterative cycles of prototype/solution testing) and usage of prototyping materials (e.g., opting to share and use recycled materials).

4.
Collaborative knowledge building and sharing: The STEM hackathon environment acts as a social learning ecosystem as students collectively work under a time crunch to problem-solve, learn from each other's expertise, and achieve a common goal. The knowledge construction process is hence collaborative in nature and requires soft skills such as communication, negotiation, compromise, and conflict resolution. The collaborative learning ecosystem could be further diversified through the formation of inter-level teams and the assignment of higher-grade mentors.

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[2] SingHealth Academy. (n.d.). SingHealth Hackathon 2023. https://www.singhealthacademy.edu.sg/migrated-content/residency/life-singhealth-residency/singhealth-hackathon-2023

[3] Teo, T. W., Mabulo, S. J. S. B., Lim, Y. S., & Santhana Raj, A. L. (2025). STEM education handbook: A guide for educators. Nanyang Technological University, National Institute of Education. https://doi.org/10.32658/10497/30334; Oyetade, K., Zuva, T., & Harmse, A. (2024). Evaluation of the impact of hackathons in education. Cogent Education, 11(1), 2392420; Nandi, A., & Mandernach, M. (2016). Hackathons as an informal learning platform. In Proceedings of the 47th ACM Technical Symposium on Computing Science Education (pp. 346–351); Falk, J. H., Randol, S. and Dierking, L .D. 2012. Understanding the informal science education landscape: An exploratory study. In Public Understanding of Science, 865-874.

[4] Briscoe, G. (2014). Digital innovation: The hackathon phenomenon. http://qmro.qmul.ac.uk/xmlui/handle/123456789/11418

(top left) A STEM capacity building event, showcasing Singapore's innovation in agriculture and technology to overseas teachers

(top right) Students exploring precision engineering at BERNINA (Singapore), organised by Temasek Foundation

(bottom) STEM Hackathon 2025, themed "STEM for Humanity," co-organised by Club Sci-Napse & meriSTEM@NIE

Did you know?

meriSTEM@NIE (the Multi-centric Education, Research and Industry STEM Centre) has actively led practitioner-focused and student-led STEM capacity building initiatives since 2019.

By leveraging on STEM programmes such as STEM hackathons, meriSTEM@NIE pairs practical learning experiences with empirical analysis and theoretical discussion, contributing to the global discourse on STEM education through a research-led lens.

SCAN TO LEARN
More about other meriSTEM@NIE partnership and outreach programmes

STEM
HACKATHON
2025
SCINAPSE & MERISTEM PRESENTS
22ND MARCH 2025
9.00AM - 4.00PM
NIE7A-01-06/07
(LIFE SCIENCES LAB 1 AND 2)
1.3480°N, 103.6791°E
SHAPING THE FUTURE

SOLVING REAL-WORLD PROBLEMS WITH TEAMWORK ACROSS DIFFERENT DISCIPLINES

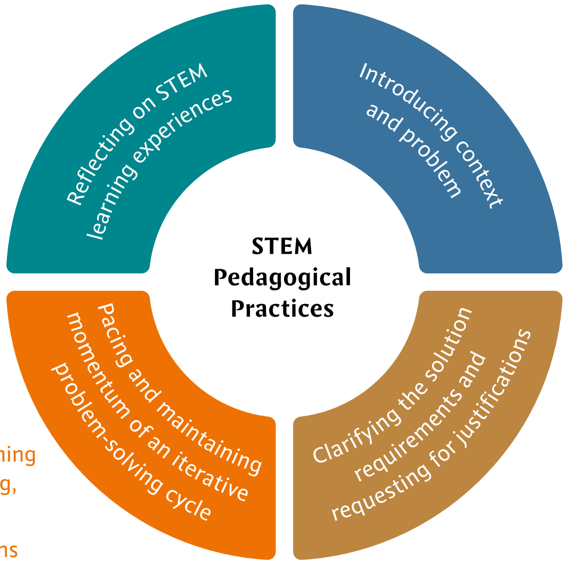
GRAB A LIMITED-EDITION STEM HACKATHON T-SHIRT AND STAND A CHANCE TO WIN EXCITING PRIZES! PLUS, ENJOY A BENTO LUNCH ON US!

SCAN THE QR CODE TO JOIN

B. Designing a STEM hackathon

The following is a non-exhaustive guided overview and practical application of how a STEM framework can be adapted to conduct a STEM hackathon. The steps adapt and interweave the four main pedagogical practices for integrated STEM learning described in Dr Teo's STEM Pedagogical Practices Framework from the STEM Education Handbook[5], offering guiding questions for teachers to reflect on the "hows" and "whys" of designing a STEM hackathon.

SCAN TO ACCESS
The STEM Pedagogical Practices Framework



- Providing heuristics for critical reflection

- Questioning
- Contextualisation
- Constructing personas

- Scaffolding (macro, meso, micro activities)
- Create familiarity with iterative cycles of designing building, testing, revising, and so on
- Setting clear expectations

- PMI (Plus-Minus-Improvement) Analysis
- KWL Analysis
- Critical examination of personal bias, assumptions, ignorance

STEM Pedagogical Practices Framework

KEYWORD

KWL technique/analysis stands for asking students what they ***Know*** about a topic (K), what they ***Want*** to know (W), and what they have ***Learnt*** (L) at the end. This simple analysis can be expressed in a table or chart for students to complete.

SCAN TO LEARN
more about KWL technique in teaching

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[5] Teo, T. W., Mabulo, S. J. S. B., Lim, Y. S., & Santhana Raj, A. L. (2025). STEM education handbook: A guide for educators. Singapore; Nanyang Technological University, National Institute of Education.

1 *Establish a clear purpose or primary goal for our hackathon and identify your target audience*

Who and what is the STEM hackathon for?

- Examples include generating novel solutions, microlearning and application of specific skills, and fostering communication and collaborative skills.
- Consider the students' knowledge and skill levels. You may wish to also consider the scale of your hackathon. Will the hackathon be a single-class, whole-grade level, or a multi-level exercise, and why?

2 *Craft the problem statement*

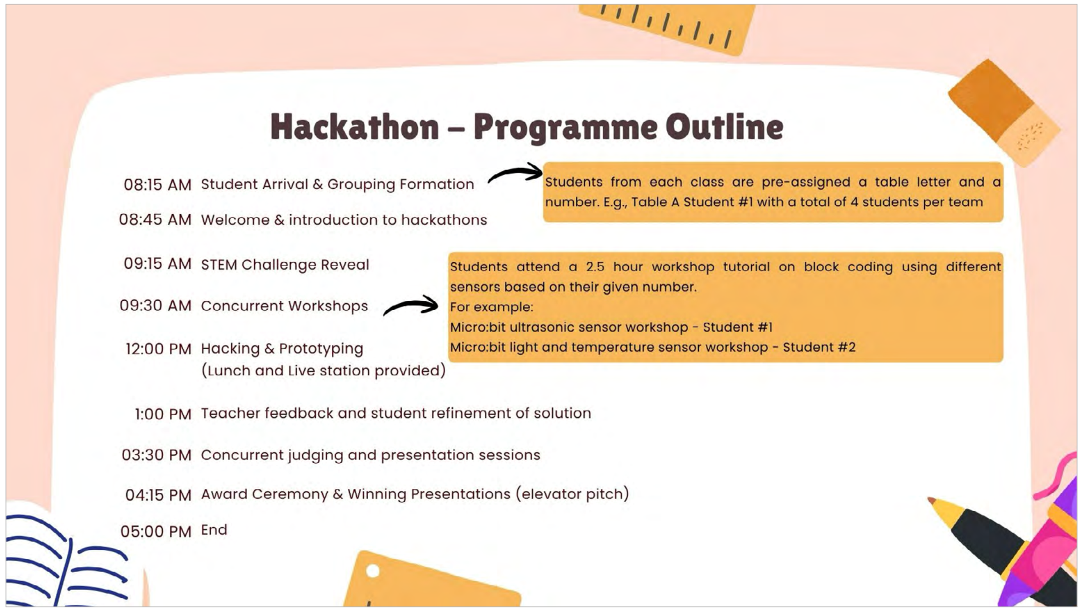
What is the problem to be solved?

- A problem or theme may be selected for several reasons such as recency and criticality of emerging affairs, issues or challenges, curricular support, pedagogical intentions (e.g., introducing computational thinking with block coding) and merits, and more. The complexity of the problem will vary depending on factors such as your target audience (prior knowledge and readiness) and the duration of the hackathon.
- Anchoring the problem in a real-world context (or theme such as the United Nations Sustainable Development Goals) aligned to students' lived experiences or interests can foster empathy and cultivate interest and motivation to solve the problem.

3 *Plan a detailed programme*

What should the hackathon entail and who are involved?

- Consider: **pedagogical practices** such as **how the context and problem/challenge is introduced; students' prior knowledge and readiness levels** and the potential need for **learning/ resource supports** such as tutorials or workshops, to level up or provide a foundational benchmark for participant skillsets (e.g., in coding of microcontrollers and sensors for prototyping (digital literacy); **hacking time (for ideation, clarification of solution requirements, prototyping, and design refinement)**; **presentation of ideas**, and more.
- Given the available budget and resources, create a detailed (in-house) programme with a breakdown of the logistics required to ensure that all operational needs are addressed. This includes adequate time for all activities and factors, such as the number and availability of staff or faculty members to facilitate participant groups as well as support on-the-ground tasks such as resolving IT issues, food and water distribution, etc. In contrast, only a brief overview of the programme is required for the target audience.



Hackathon – Programme Outline

08:15 AM	Student Arrival & Grouping Formation
08:45 AM	Welcome & introduction to hackathons
09:15 AM	STEM Challenge Reveal
09:30 AM	Concurrent Workshops
12:00 PM	Hacking & Prototyping (Lunch and Live station provided)
1:00 PM	Teacher feedback and student refinement of solution
03:30 PM	Concurrent judging and presentation sessions
04:15 PM	Award Ceremony & Winning Presentations (elevator pitch)
05:00 PM	End

Students from each class are pre-assigned a table letter and a number. E.g., Table A Student #1 with a total of 4 students per team

Students attend a 2.5 hour workshop tutorial on block coding using different sensors based on their given number.
For example:
Micro:bit ultrasonic sensor workshop - Student #1
Micro:bit light and temperature sensor workshop - Student #2

Example of internal programme slide showing a brief overview of the programme for a grade-level wide hackathon with instructional guiding notes for teachers

When and where should the hackathon be held?

- Choose a venue of an appropriate size that is suitable for collaborative learning. This can vary from a school hall for whole-grade level hackathons, to a science laboratory/classroom for single-class hackathons.

4 *Gather feedback*

How can the hackathon be improved for future cycles?

- **Seek students' reflections** to understand their learning experiences, readiness to problem-solve (e.g., before and after attending a workshop or tutorial), suitability of the hackathon duration, usefulness of the resources and challenging points (such as clarity of the problem statement).
- **Consolidate responses from supporting personnel** to consolidate areas of improvement such as the need for an increase in manpower or better student support — such as through the provision of onsite self-paced microlearning modules — to steer students towards more self-directed learning and offload teacher demand.

While the steps for designing a STEM hackathon have been numerically outlined, the journey of planning a hackathon and its subsequent cycles may not be linear in nature, but rather cyclical and iterative. This refinement and adaptive process is essential for creating a thoughtfully-designed STEM hackathon. When designed correctly, hackathons are a powerful and dynamic pedagogical platform that provides a glimpse into and cultivates a mindset ready for the STEM workforce.

Tips

1. **Hackathon design and implementation support**
    - Recruit a diverse support team with areas of different expertise. Invite them to take part in the brainstorming and planning process.
    - Having team members with various strengths is also important for even distribution of duties and responsibilities during the hackathon or extended project. For example, for full-day, whole-grade level hackathons, you may wish to include tech-savvy individuals to assist with the audio and tech-based setups, troubleshoot technological issues, and ensure the events in the hackathon begin and end in a timely manner.
2. **Incentivising participation and engagement**

    The success of a hackathon lies in participants having an invested interest. Consider what incentives can be offered to engage and motivate participants to immerse themselves in the experience.

    For example, you may wish to:
    - Ensure adequate supply of food and drinks. Introducing snack carts or live stations at appropriate junctions during a full-day hackathon can keep participants energised.
    - Integrate an element of a competition by means of an award or prize money. Organising prizes that appeal to participants' interests can encourage healthy competition and help develop 21st-century skills such as collaboration.
    - Consider sponsorship from industry partners for awards and prizes. Integrating industry involvement not only significantly enhances the impact of the event, but also has synergistic effects for the participants and sponsors. These include but are not limited to access to cutting-edge tools, expert advice and mentorship, alignment of solutions to market/industry needs, downstream internship opportunities for participants, and early talent recruitment for industry partners.

Conclusion

STEM hackathons offer a rich array of experiential and learning affordances, shifting students away from the traditional subject-specific siloed front-facing classroom towards a more interdisciplinary, student-oriented, agentic culture of learning, resilience, and reflection.

As a STEM hackathon is inherently dynamic in nature, designing a successful hackathon also involves anticipation of potential challenges and pedagogical strategies to mitigate them.

When conducting a STEM hackathon for the first time, fostering collaboration and peer teaching and learning can be difficult.

Strategies to address these hurdles include providing:

1. **A resource supermarket**: Implementing resource constraints by providing vouchers to redeem at a "resource supermarket" can foster collaboration through collective negotiation. Since resources are finite, group members must prioritise, justify, and come to a consensus on the critical components. This limitation reduces wastage and encourages creative problem-solving such as inter-group bargaining and/or exchange of materials.
2. **Expert consultations**: Providing vouchers for expert consultations during a given time frame helps students appreciate time and knowledge as tangible resources and currencies. As consultation windows are limited by both availability and voucher balance, students are encouraged to take ownership of their learning in various ways.

These strategies prompt more active engagement in the prototyping and troubleshooting process before seeking help, and encourage the assignment of specific roles such as lead inquirer, technical scribe, and target user, to ensure the expert interactions are maximised and shared with each other through peer teaching.

Author's reflection

As scale, resource management, and time are important considerations in a hackathon, class-level hackathons may offer a strategic starting point as these require significantly less manpower and are more manageable than large-scale (e.g., grade level) events. At the class level, you may consider an alternative to conducting concurrent workshops such as self-paced learning modules, in which a team of four can be split into two groups, with student pairs undergoing one of two self-paced learning modules. Students then return to their teams as experts of their module. Later access to both modules can be given to facilitate a more holistic learning experience.

Dr Melissa Neo

Section 2

Immediate and Familiar Spaces as Sites of STEM Learning

This section positions students' everyday environment as an accessible and authentic starting point for STEM instruction and learning. By anchoring lessons within familiar spaces such as one's home or school grounds, students are given the agency to observe their surroundings critically and make more tangible connections between abstract concepts to daily artefacts and applications. This supports deeper understanding of the interconnected world around them.

By situating students' learning in the very environment they frequent or inhabit, this lowers the barrier to entry because students can begin from a position of existing knowledge. This reduces the cognitive load, allowing students to focus on inquiry and application rather than acclimating to a new setting. In addition, hands-on investigation through observation, touch, measurement, and data collection makes abstract concepts visible and relevant to their daily lives. Lastly, the chapters in this section demonstrate various ways in which STEM inquiry is accessible to all regardless of availability of costly materials and equipment.

When reading this section, consider:

- What specific STEM assets are present on your school grounds or in students' homes?
- How do the core STEM concepts in this chapter connect to a specific, observable phenomenon within your students' everyday lives?

2.1

Discovering “My Home” Through Project-Based Learning

Ms Jidlada Manora & Ms Nicharee Pramualsab

INSTITUTIONAL PROFILE

Starfish School

LOCATION
Chiang Mai, Thailand

TYPE OF INSTITUTION
Private early childhood and primary school

LESSON DETAILS

NUMBER OF LESSONS
210 lessons (21 weeks, 5 days a week, 2 lessons a day)

DURATION
45 mins/ lesson

GRADE LEVEL
Kindergarten

SUBJECT/ DISCIPLINE
Languages (Thai, English), Science, Mathematics, Makerspace, Music

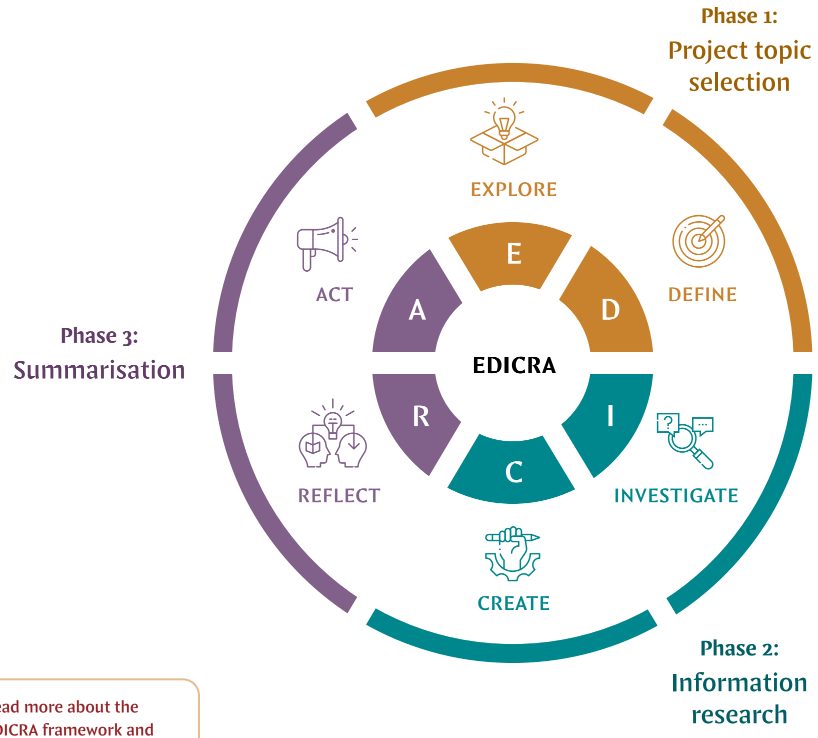
NO. OF STUDENTS/ PARTICIPANTS
20

STUDENT READINESS
Mixed ability

Introducing integrated STEM learning to early childhood learners can be achieved through project-based learning modules, where students gradually develop an understanding of the world around them. This chapter provides a detailed rundown of how the EDICRA framework was used in a full semester of project-based learning for early childhood learners, focusing on collaboration and hands-on learning, culminating in a student-led project exhibition on the topic “My Home”.

In this chapter, we learn:

- ✓ How the three phases of the EDICRA framework were implemented in a curriculum for early childhood learners
- ✓ How to guide early childhood learners through a curriculum of integrated STEM in a relatable and age-appropriate way
- ✓ How to accommodate a diverse class of learners with different ethnic backgrounds and language abilities



Read more about the EDICRA framework and how it functions in chapter 1.3 of the book!

The EDICRA Learning Framework

By Dr Nanthaporn Prae Seributra,
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EDICRA is an instructional framework designed to promote effective teaching and learning. It trains students to practise self-directed learning as they plan their work, develop systematic working habits, and engage in hands-on activities to construct knowledge independently. The framework was developed by Dr Nanthaporn Janchalia Seributra, Chief Executive Officer of the Starfish Education Foundation, for both early childhood and primary school learning contexts, following a three-phase or six-phase learning process, respectively. This chapter demonstrates how teachers at Starfish School used the three-phase EDICRA framework in a project-based learning module as a means of incorporating integrated STEM and teaching a diverse class of students at an early childhood level.

Key features of the EDICRA learning process include:

- Empowering student ownership of their own learning; students planned their learning and solved issues based on interests and problems of their choice
- Developing students’ cognitive and soft skills, such as planning, problem-solving, and social-emotional skills, fostering innovations that are contextually relevant and bring positive change to their communities
- Encouraging students to think critically, be media-literate, and creatively utilise technology for their learning

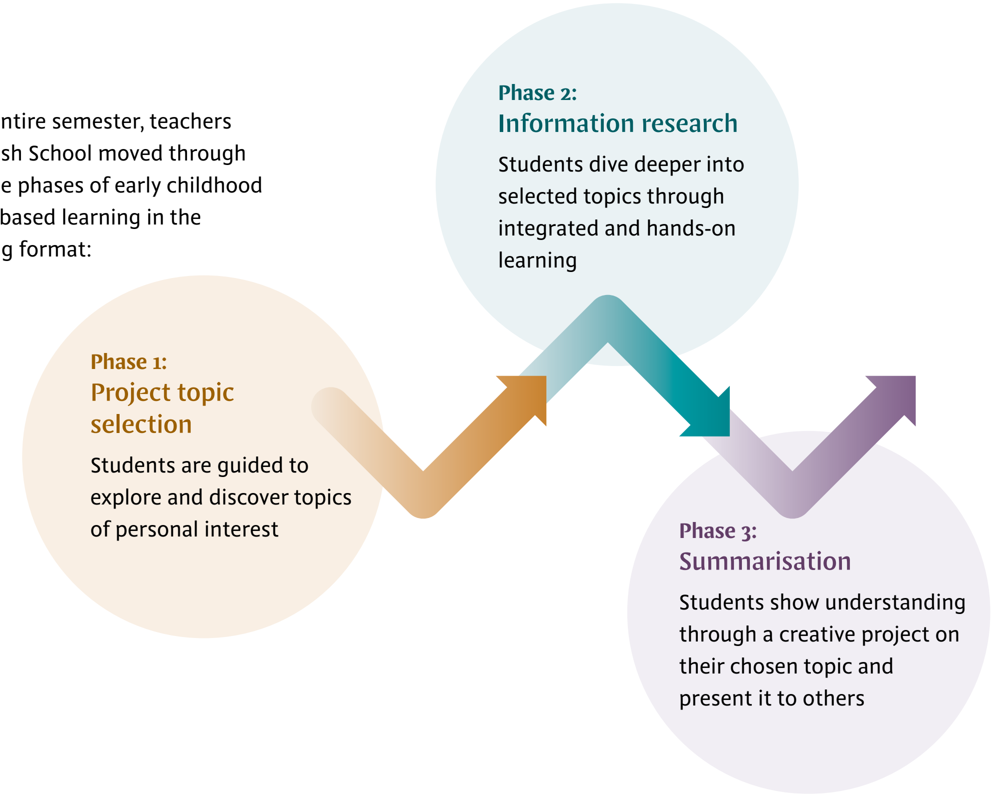
The EDICRA framework was implemented in Starfish School’s kindergarten curriculum, according to the following schedule:

Level	*Subject*	*Hours/week*
Kindergarten	Thai language	5
	Mathematics	5
	English	5
	Project-based learning	**10**
	Makerspace	2
	Sports & play	3

Number of weeks spent on each phase in one semester (20 weeks in total):

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Kindergarten	Phase 1			Phase 2												Phase 3				

For an entire semester, teachers at Starfish School moved through the three phases of early childhood project-based learning in the following format:



Phase 1:
Project topic selection
Students are guided to explore and discover topics of personal interest

Phase 2:
Information research
Students dive deeper into selected topics through integrated and hands-on learning

Phase 3:
Summarisation
Students show understanding through a creative project on their chosen topic and present it to others

This three-step process enabled every early childhood learner to experience balanced and holistic development across physical, emotional, mental, social, and intellectual domains, while cultivating a positive attitude towards their local contexts. This approach fostered curiosity, encouraged joyful learning, and helped learners reach their full potential.

Topics covered in this semester	
Understanding the topic of “My Home”	
Science	• Explored building materials (wood, paper, plastic), testing their strength and water resistance • Observed animal homes (bird and ant nests) around the school • Discussed why people and animals need homes
Technology	• Conducted information searches using computers and search engines • Used drawing applications to design houses
Mathematics	• Learned and applied arithmetic skills through counting, addition, and comparing the **number of features** in/of a house • Applied the concepts of greater than, less than, and equal to, by using the number of features in/of a house • Applied simple geometric shapes to design houses
Makerspace	• **Art room:** Built and decorated ice cream stick houses • **Workshop room:** Built wooden block houses using children-friendly tools such as plastic hammers and oversized screws • **Studio room:** Designed houses with drawing applications using an iPad
Languages	• **Listening:** Gained knowledge from diverse media sources including the internet (videos and other digital content), songs, stories, and visual aids about “My Home” • **Speaking:** Developed topic-specific vocabulary to articulate ideas and descriptions relating to houses • **Reading comprehension:** Retrieved information about different types of houses from text • **Writing:** Developed composition skills by summarising ideas from topic-specific stories
Music	• Developed skills in singing, rhythm, and tempo to promote musical expression • Strengthened auditory memory and coordination through song performance and movement • Demonstrated collaborative skills during rehearsals and performance of the song “This is My House”

Curriculum plan

Understanding “My Home” through a semester of project-based learning

In this semester, students engaged in activities that foster key STEM competencies and skills for further development in their primary school years.

i. Desired learning outcomes and objectives

1. Self-exploration Preparation for sharing and reflecting on the project	Students collaborate to plan an exhibition to showcase their learning processes, activities, and discoveries to parents and peers.
2. Field work Project evaluation through the eyes of others	Students clearly and comprehensively explain the steps involved in their activities.
3. Knowledge reflection Synthesising and summarising learning to share with others	Students reflect on what they have learned and demonstrate their understanding through various creative means, such as drawing, using modelling clay, art collages, constructing model houses, and writing and reciting rhymes.
4. Inquiry Generating new questions	Teachers and students engage in discussions to ensure the inquiry process addresses the students’ questions and curiosities thoroughly.
5. Exhibition Summarising learning from the entire project	Students present their work and what they have learned under the theme “My Home”. Students also describe their learning and the relevant activities and learning experiences encountered.

Specific instructional objectives

1. Nurture students to develop the capacity for independent inquiry and self-directed learning, particularly in areas of personal interest.

2. Encourage students to develop the ability to plan their work systematically and engage in every step of the process through hands-on experiences. For example, before starting an activity, teachers can model the steps and materials used before prompting students to recall the steps and consider why they are ordered sequentially. Students can then be given the autonomy to modify the steps and materials used to create their models.

ii. Carrying out the curriculum

PHASE 1

Project topic selection

a. Topic discussion

In the first phase, students and teachers engaged in a discussion to select a topic that the students wish to investigate. This phase also allowed the teacher to gain insights into the children’s prior knowledge of the topics they wished to explore.

Tip

The chosen topic should be one that the students are somewhat familiar with, allows for integration across different subject areas, and is suitable for a study period of one week.

First, the teacher initiated a conversation on potential topics students might be interested in learning. While the students were able to identify the topics they wished to learn they were often unable to articulate the rationale for their selections. Teacher guidance and direction was needed to help them scope their interests.

Sentence starters offered by the teachers helped students articulate their reasoning with greater clarity and confidence.

> ***Sentence starters:***
> *“I want to learn about... because...”*
> *“This topic is important to me because...”*
> *“I am curious about... since...”*

b. Topic exploration

The next step was to broaden students' knowledge of topics that piqued their interests. Topic selection occurred over two separate sessions.

Session 1

The teacher led the students on an exploratory walk around the school. Afterwards, students drew and coloured pictures representing what they wanted to learn, following a discussion with their teacher.

Session 2

The children watched a documentary on the three shortlisted topics — houses, flowers, and watermelons. Afterwards, the teacher guided a discussion on what they would like to learn from each topic. Students then shared their ideas and interests and created a collage (a paper tearing and pasting activity) to represent what they wanted to explore further.

This process occurred over two weeks, during which students were given opportunities to develop their thinking and decision-making skills by **formulating questions** and using language to **express and explain** their interests. They also learned to **listen** to their peers' rationale behind their choices.

(top to bottom): 1. Students on a school walkabout; 2. Students drawing what they wanted to learn; 3. Students watching a video to explore three shortlisted topics — houses, flowers, and watermelons.

(right) Students creating an art collage on their topic of interest

Teaching for diversity

At Starfish School, a single classroom can comprise as many as nine different ethnic groups. Some of the ways student diversity was supported in this lesson include involving students in the planning and decision-making process of their exhibition and structuring the challenge based on their interests.

Since communication with some students was at times challenging, teachers provided multiple learning resources to support students' understanding, articulation, and concretisation of new or unfamiliar terms. Students were also encouraged to engage with the school's dynamic environment of experiential and contextual learning, fostering a meaningful connection between the curriculum and their daily lives.

c. Topic shortlisting and voting

To help students narrow down their preferred topic as a class, the teacher engaged students in a guided conversation, taking time to relate students' lived experiences and environments back to each topic. Students then voted by drawing and colouring in a picture of what they wanted to study most.

A voting chart was used to record students' choices. The chart also served as a learning opportunity for understanding numerical concepts such as greater than, less than, and equal to. "My Home" received the most votes as the students' topic of preference.

(top) Students voting for their preferred topic

(bottom) The voting chart

Students' drawings reflecting their prior knowledge on homes

d. Demonstrating prior knowledge

Students' prior knowledge was elicited through their descriptions of various aspects of a home. These included but were not limited to subtopics such as the different rooms in their home, other elements (natural or manmade) surrounding their homes such as the landscape, and the shapes and forms of other houses, home safety precautions, household items (e.g., cleaning tools) and more. Students also shared about the significance of having a home and the people and places within their environment.

To further support students' communication skills, teachers encouraged peer-to-peer inquiry, prompting them to voice their curiosities and generate new questions based on peer sharing, fostering a learning environment that cultivated both exploration and diversity through student-driven inquiry.

PHASE 2

Information research on “My Home”

This is the core phase of the EDICRA project-based learning process, lasting 13 weeks.

It involves the investigation and exploration of information through various sources and methods, such as reading books, conducting field studies, listening to guest speakers, and more. The goal is for students to formulate hypotheses and test them to find answers to their questions. For example, the entire class watched a documentary and had the opportunity to formulate and direct their questions to experts.

Teachers led students through the following activities over 13 weeks:

a. Engaging with the school community and sourcing information from documentaries

Students engaged in conversations with school staff of varying roles to broaden their understanding of the topic. For instance, they interviewed the school’s maintenance worker, who explained the use of construction tools and building materials. He provided knowledge about the structural components of a house, such as the roof, door, windows, and common construction materials including cement, wood, stone, and bricks.

Students also interviewed the cleaning staff, who introduced them to cleaning tools such as brooms, mops, and dusters.

Lastly, students explored housing diversity through documentaries and other visual resources on different housing types (e.g., single-storey or double-storey houses, and wooden, concrete, and mobile houses).

Students on a field trip to the Lanna Traditional House Museum

b. Field trip

To immerse students in authentic culturally-relevant experiences, teachers brought students on a field trip to the Lanna Traditional House Museum at the Center for the Promotion of Arts and Culture, Chiang Mai. Here, students explored the different houses featured in the museum and gathered information by asking questions.

c. Hands-on activities to understand houses

Throughout Phase 2, teachers integrated hands-on creative activities such as making collages, clay modelling, drawing and colouring, and assembling model houses. This allowed students to process and represent the information they learned about houses and homes in a playful and age-appropriate manner.

Pedagogical considerations

During this phase, the teacher played a crucial role, not only in providing access to the relevant learning resources but also as a knowledgeable other during the inquiry process. This ensured that students accessed the appropriate information and materials safely to carry out their research.

Students were split into groups to pursue different activities. For example, while a group created drawings and paintings, others made collages or clay houses. Teachers also involved parents by inviting them to co-create model houses at home with the students using recycled materials.

Students creating their model houses

PHASE 3

Summary and showcase

This phase focused on students reviewing, consolidating, and presenting the knowledge that they gathered over the semester in the form of a final exhibition. The exhibition was open to parents, teachers, staff, and school personnel. During this preparation, students learned to plan and organise their presentations and develop their communication skills through revisiting key questions and using the appropriate terms to construct their sentences. The exhibition was an opportunity for students to develop confidence in expressing themselves and speak in public settings.

An example of the exhibition activities are as follows:

Exhibition activities	Instructional approach	Preparatory activities
Preparation for the "My Home" exhibition	Student-centred and teacher-supported	After subtopic selection (e.g., materials for a roof), teachers consolidated the content and guided students as they rehearsed their presentations. Teachers also prepared visual aids and supplementary media so that children could explain their subtopics more clearly and confidently to parents and other visitors.
Creating project-based learning materials and preparing tools and props for the exhibition	Teacher-led and student-supported	Teachers prepared supporting media (e.g., posters, videos, flashcards) required to support class activities, such as students decorating their own drawings according to their subtopics.
Explaining the steps and activities involved in the project	Teacher-led and student-supported	The teacher reviewed the key steps of the project with the class to aid students as they revisited their key questions in small groups and practised summarising what they had learned.
Organising bulletin boards and displaying creative project work	Student-led and teacher-supported	Students decorated and arranged bulletin boards to showcase their collages, drawings, and models. Teachers helped with the layout and displays as needed.
Performing the song "This is My House"	Student-led	Students performed together using rhymes, songs, and rhythmic movement to integrate their subtopic into the performance.
Hosting the "My Home" project exhibition	Student-led and teacher-supported	Students presented their work to parents and visitors, while teachers offered support by organising the schedule, facilitating the event, and ensuring a smooth transition of activities on the event day.

Students received support from teachers in two key ways:

1. **Preparation of visual aids:** Teachers prepared posters, visual boards, and flashcards to showcase students' work and facilitate their presentations.
2. **Communication of students' ideas:** Teachers guided students in organising and summarising key points for their presentations, providing opportunities for presentation rehearsals, and modelling how to speak clearly, maintain eye contact, and use gestures to augment their presentations.

Students first practised in small groups before presenting their work to the class. They were organised according to the subtopics selected in Phase 2 (e.g., types of houses, building materials, rooms in a house, and home safety). Each group was responsible for designing and managing their presentation, with teachers serving as facilitators. Teachers also prepared supporting materials for each subtopic so that students could practise at home with their parents, enabling families to be active participants in the students' preparation.

Students organising bulletin boards and displaying creative project work

Developing confidence in language skills

Performing the song "This is My House" strengthened students' language and articulation. The song's regular and easy-to-follow rhythm provided a low-anxiety scaffold for practising topic-specific vocabulary, prosody (i.e., stress and intonation), and phonetic clarity. Furthermore, students' art presentations (clay models, collages, drawings/paintings) required students to narrate their ideas and steps. This activity encouraged students to integrate newly learned vocabulary with the use of sequencing and temporal markers (i.e., first–next–finally) to foster language expression, self-esteem, and confidence in oral communication.

Students performing the song "This is my Home"

The exhibition was held in the school hall, where students' creative works were displayed on bulletin boards and tables. Stage performances such as rhymes, songs, and dances on the theme of "My Home" were organised in groups, with teachers coordinating the sequence of presentations to ensure a smooth flow.

Large numbers of parents, teachers, and staff attended the event. Parents responded warmly and proudly, praising their children's confidence and creativity, and expressing appreciation for the opportunity to witness their children's learning journey being presented in such a meaningful way.

iii. Challenges and solutions in lesson implementation

Challenge	Positive solution
The majority of the kindergarten students come from ethnic minority backgrounds and face challenges in communicating fluently in Thai.	Visual aids and local sign language/gestures can be used to support comprehension. One can encourage peer support by allowing students who share the same ethnic language to translate for their classmates. This approach not only improves students' understanding but also promotes collaboration and inclusivity in the classroom.
Preparing students for the 21st century and empowering them to take ownership of their learning with equitable access to quality education can be challenging.	As language can be a barrier, equitable access to quality education can be provided by using visual and hands-on learning materials, integrating play-based activities, and providing opportunities for children to choose their topics of interest. We also encourage peer support among classmates with teachers acting as facilitators by preparing resources and acting as guides to support group/class discussions. Through these strategies, young learners are nurtured to explore topics/activities more independently and develop 21st-century skills in age-appropriate ways, to gradually take ownership of their own learning.

Authors' reflections

Students demonstrated interest and cooperation in the learning activities, showing curiosity and enthusiasm when exploring topics related to "My Home". They actively engaged in asking and answering questions that they were eager to learn more about. Students showed particular interest in hands-on activities such as craft- and rhythm-based movement or dance. However, when it came to presenting their work, some students lacked confidence, speaking softly, unclearly, or hesitating to express themselves. They struggled to recall what they were presenting and showed signs of low self-assurance during rehearsals.

To help build students' confidence, teachers organised multiple rehearsal sessions in small groups prior to the final presentation. Visual materials, videos, and handmade teaching aids were used to support recall of key points. Teachers also modelled essential presentation skills and offered consistent positive reinforcement to encourage hesitant learners. Lastly, students performed in groups through song and rhymes, enabling them to feel supported by their peers while gradually developing the self-confidence to present individually and in public.

Ms Jidlada Manora & Ms Nicharee Pramualsab

2.2

Reaching for the Sky: Applied Geometry in Measuring Buildings & Trees

Mr Leo Andrei Crisologo

As students progress through their mathematical learning journey, lessons can become increasingly abstract and difficult for students to see its relevance in their daily lives. How do we teach concepts like trigonometry and still ground them in students' lived experiences? In this lesson, Mr Leo leads his students in understanding and applying basic trigonometric principles of tangents to calculate the heights of buildings and objects around the school campus. In addition, he interweaves an interdisciplinary element by introducing students to the Global Learning and Observations to Benefit the Environment (GLOBE) programme's Biometry Protocol to apply the mathematical skill of measurement and scientific skill of real-world data collection.

In this chapter, we learn:

- ✓ The basics of trigonometry and how to apply the tangent function to calculate the heights of buildings and trees
- ✓ How to build and use your own clinometer
- ✓ How to integrate the GLOBE programme's Biometry Protocol into an applied Mathematics lesson

INSTITUTIONAL PROFILE

Philippine Science High School (Main Campus)

LOCATION
Quezon City, Philippines

TYPE OF INSTITUTION
Scholarship Science High School

LESSON DETAILS

NUMBER OF LESSONS
1 lesson

DURATION
45–60 mins/ lesson

GRADE LEVEL
Grades 9 & 10

SUBJECT/ DISCIPLINE
Mathematics, Environmental Science, Engineering Design

NO. OF STUDENTS/ PARTICIPANTS
10–40

STUDENT READINESS
Mixed to high ability

The Global Learning and Observations to Benefit the Environment (GLOBE) programme is an international Science and education programme that provides students and the public worldwide with the opportunity to engage in the scientific process of data collection.

One of the challenges in teaching high school Mathematics is connecting mathematical concepts to real-world contexts and applications that students can appreciate. While worded problems are typically used to contextualise a topic, incorporating more tangible real-world applications can enhance student engagement in the lesson.

In this lesson, Mr Leo challenged students to employ the GLOBE programme's Biometry Protocol to measure the heights of tall objects (such as trees and buildings), use available tools such as metresticks and protractors, and apply introductory concepts in trigonometry to help students gain a deeper understanding of trigonometry and real-world data collection.

For campuses with ample green spaces, such as the Philippine Science High School Main Campus, this activity was an excellent opportunity to make purposeful connections between Mathematics and environmental education. The GLOBE programme's Biometry Protocol encouraged students to collect and report ecological data. Through the systematic collection of biometric data such as tree height, species, diameter at breast height, location coordinates, and ground cover, students could compile valuable conservation information on their local environment.

This interdisciplinary activity not only highlighted how Mathematics can be used in real-world contexts but also encouraged students to contribute to real-world scientific data collection as responsible citizen scientists.

Students measuring the heights of trees using their self-made clinometers

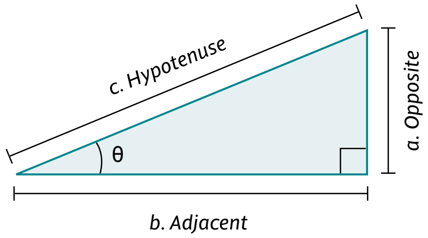
Topics covered in this lesson

Mathematics	Environmental Science (via the GLOBE programme's Biometry Protocol)
• Right angle trigonometry (focusing on the tangent function) • Measuring and interpreting angles of elevation • Estimation and measurement • Error analysis, identifying sources of error, and discussing precision and accuracy	• Data collection (focusing on measuring tree height using mathematical methods and the inclusion of additional data such as tree species and ground cover) • Application of standard protocols on classification and monitoring • Environmental conservation and citizen science

Trigonometric functions

Trigonometry is the branch of Mathematics concerned with specific functions of angles (mostly in the context of a right-angled triangle), and their variety of applications in problem-solving. There are six commonly used functions of an angle:

Function	*Relationship to sides of a right-angled triangle*
1. Sine (sin)	sin θ = a/c
2. Cosine (cos)	cos θ = b/c
3. Tangent (tan)	tan θ = a/b
4. Cosecant (cosec)	cosec θ = c/a
5. Secant (sec)	sec θ = c/b
6. Cotangent (cot)	cot θ = b/a



SCAN TO LEARN
More about trigonometry and trigonometric functions

These functions represent the ratios of one side of the triangle to another and can be used in various applications in engineering and physics. This lesson focused on using the tangent function and the aid of a clinometer to calculate the heights of objects.

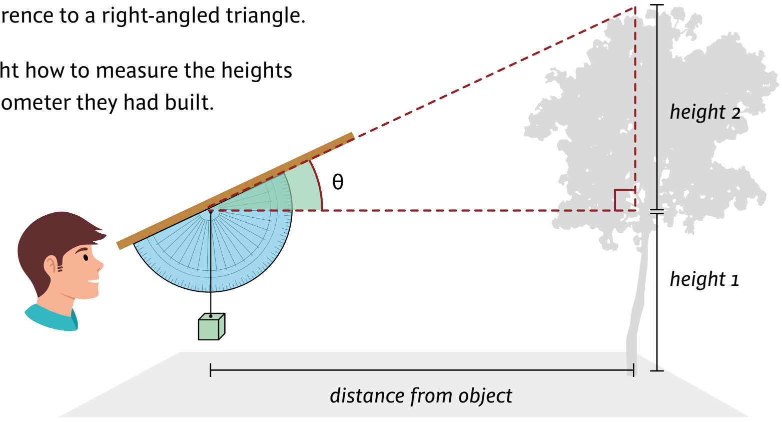
The GLOBE programme’s Biometry Protocol

SCAN TO LEARN
More about the Biometry Protocol and access downloadable teaching guides

Biometry is the measurement of living things, such as tree height and circumference, canopy cover, and biomass. The GLOBE programme’s Biometry Protocol presented a series of guiding questions, steps, and instruments required to conduct a lesson that incorporates biometry.

Clinometers are a common tool used in biometry as a measuring device for angles. A clinometer allows you to measure the angle of elevation, angle from the ground, or an angle of an object, with reference to a right-angled triangle.

In this lesson, students were taught how to measure the heights of trees and buildings using a clinometer they had built.



Example of how a clinometer is used to calculate the height of an object

Lesson plan

Using trigonometry to measure the heights of buildings and trees

In this lesson, Mr Leo introduced the concept of trigonometry to his students and provided them with an opportunity to apply these concepts to calculate the heights of buildings and trees around their school. Students were also guided to use the GLOBE programme’s Biometry Protocol to gather other data on the foliage around campus, using the same measurement techniques.

i. Desired learning outcomes and objectives

1. Mathematical skill	Students demonstrate a conceptual understanding of trigonometric ratios, and apply the tangent function to calculate real-world measurements/dimensions.
2. Environmental Science	Students identify how environmental data (obtained using the GLOBE programme’s Biometry Protocol) can contribute to global environmental monitoring and understanding of the importance of biodiversity in their local context.
3. Mensuration	Students construct and use a clinometer to measure angles of elevation and apply trigonometric principles to compute the heights of trees and buildings.
4. Data analysis	Students record mathematical and biometric data, analyse results, and identify sources of error.
5. 21st-century skills	Students demonstrate critical thinking; problem-solving; collaboration and communication skills; ability to use information and communications technology; environmental literacy; and being a pro-active self-directed learner.

ii. Carrying out the lesson

Preparation of tools

Mr Leo's students were encouraged to build their own clinometers for this lesson. This step can be assigned as homework with guided instructions.

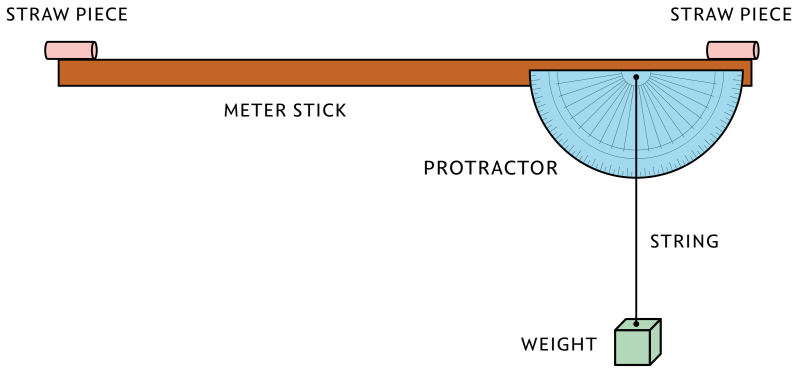
#0 Construction of a clinometer

Materials required (1 set per group):

- *Protractor*
- *Metrestick*
- *String*
- *Weight (e.g., slotted weight[s] to be tied at the end of the string)*
- *Straw (paper or plastic)*
- *Strong adhesive (e.g., super glue) or tape*
- *Mini portable electric drill, or paperclip*

Supplementary materials:

- *Tape measure (10–15 metres)*
- *Notebook for data recording*



ⓐ Start constructing the clinometer by attaching the base of the protractor to one end of the metrestick. You may drill a small hole in the centre of the protractor using a mini portable electric drill to attach the string. Teachers must ensure that students using the electric drill are supervised, or the teacher may choose to pre-drill the hole before the lesson.

Tip

Another way to punch a hole in the protractor is to heat the end of a paperclip and press the heated tip down onto the plastic protractor!

When using adhesives, stronger adhesives (such as super glue) will make a sturdy clinometer, but will render the protractor and metrestick unusable after because they cannot be taken apart; whereas using string or tape to bind the protractor and metrestick may lead to a flimsier clinometer design.

ⓑ Attach a piece of string to the centre of the protractor. At the other end of the string, attach a weight. Ensure the weight is heavy enough to ensure it is not affected by wind when the clinometer is used, but light enough to not be easily dislodged from the tool. Slotted weights are recommended.

ⓒ Cut pieces of straw approximately 1 inch in length and attach them to both ends of the metrestick. These will serve as the sights of the clinometer. Refer to the diagram in this section for the expected appearance of the clinometer.

Tip

Common weights to consider can be slotted weights, coins with a hole in the middle, or keys tied together.

Pedagogical considerations

- Constructing the clinometer from simple materials can help students understand how the tool works and how it is grounded in basic Geometry and Physics concepts.
- Allowing students to make errors and then make subsequent adjustments to their clinometers helps develop scientific inquiry and critical thinking through trial and error.

Students were free to use their own materials in constructing their clinometer, which meant the clinometers differed in appearance. For example, while some used a shorter stick instead of a wooden metrestick, others used string of different lengths. The differences in the materials used, the design process, and the effectiveness of the clinometer designs served as additional points for class discussion.

Main activity: Measurement of heights of tall objects around school

#1 Teacher preparation

ⓐ Ideally, the teacher should have the measurements of the objects to be measured. In the event that the data is not available, the teacher should have an estimation of the measurements.

ⓑ Introduce the six trigonometric functions as the ratio of the sides of a right triangle. Guide the students to identify how the height of an object should be measured before beginning the data collection activity.

SCAN TO LEARN
The guide sheet on using clinometers

#2
Forming groups

a Group the class into threes. Each group should have their own clinometer and notebook.

b Assign roles to the students such that each group has a clinometer sighter, a measurement reader, and a record keeper.

#3
Measuring objects around school

a Bring students around your campus and identify the object to be measured.

b Find a convenient location for measuring the object. Ensure that there is an unobstructed view of the top of the object and an unobstructed path to the object such that students can measure the object from its base. Let this be point A.

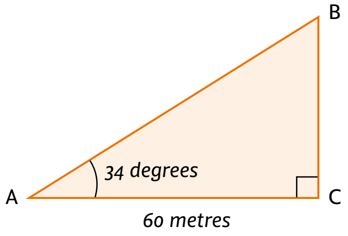
c The measurement reader then uses the tape measure to obtain the distance from the base of the object to point A. Record this measurement.

d The clinometer sighter looks through the straws on the clinometer to sight the top of the object. The measurement reader should carefully wait for the weighted string to stop moving before reading the acute angle measurement on the protractor. The reading should then be recorded.

e Each group should conduct three or more measurements. Encourage students to change their distance from the object and get different clinometer readings to see if the computed height will remain the same.

f Using the measurements and a calculator, compute the height of the object using the following formula:

$$\text{height} = \frac{\text{distance from object}}{\tan\text{ (acute angle measurement)}}$$



$\tan A = BC/AC$ $\tan 34 = BC/60m$ $BC = 60m \times \tan 34$

Students measuring the heights of buildings around campus

#4
Discussion and sharing

a After the activity, invite students to compare and discuss their results and identify possible sources of error in their measurements.

Pedagogical considerations

- This activity provides a real-world context for the application of abstract mathematical concepts such as the tangent function and angles of elevation.
- As the activity is grounded in real-world, tangible experiences, errors in measurements will occur. This provides an avenue for developing students' critical thinking and problem-solving skills as they use the numeracy skills learnt in Mathematics to determine whether their measurements are reasonable and infer possible sources of error.

Supplementary activity: GLOBE programme's Biometry Protocol

1. Refer to the complete GLOBE programme's Biometry Protocol and assess which components can be conducted by the students within their learning environment.
2. If the students measured tree heights in the first activity, they could continue measuring (1) canopy and ground cover, (2) tree circumference, and (3) graminoid biomass.
3. The activities and worksheets for carrying out the protocol can be accessed by scanning the QR code.

SCAN TO LEARN
The GLOBE Programme Biometry Protocol

Pedagogical considerations

- Expanding the mathematical activity to include the GLOBE programme's Biometry Protocol transforms a monodisciplinary lesson into an interdisciplinary one, integrating Mathematics with Environmental Science.
- The activity can foster a sense of social and scientific responsibility as students interact with their environment and collaborate to obtain measurements that contribute to global datasets, as well as apply them to make calculations to evaluate their measurements.

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iii. Challenges and solutions in lesson implementation

Challenge	Potential solution
As this is an outdoor activity, there is a risk of disruption due to inclement weather. While it would be ideal to schedule the activity during dry seasons, it also needs to align with the curriculum's schedule.	If the weather is not ideal, the teacher can designate this as an enrichment activity even after the lesson on the right triangle trigonometry has passed.
A lack of familiarity with the typical heights of common objects or the absence of a realistic benchmark for the heights of these objects, can lead to significant overestimation and acceptance of inaccurate measurements. For example, students may accept measurements of 18 to 22 metres for a four-storey building that is 15 metres in height.	To help students verify the accuracy of their measurements, teachers should obtain accurate data of the object's measurements from reliable sources and conduct their own measurements. Alternatively, teachers can provide students with reference points such as the clearance height of an overpass on a highway or the entrance to a covered parking area (typically around 4.5 metres). This allows students to use an established benchmark to assess if their measurements are proportional to a known dimension.
The class may not have access to adequate open spaces, which are safe for conducting this activity.	Secure support from school administration to provide transportation, additional personnel, or to set aside a schedule for the class to conduct this activity in more appropriate spaces, such as outside the campus.
There is increased difficulty in managing a class outdoors in non-formal learning spaces.	Set clear expectations and ground rules prior to conducting the activity.

Author's reflections

Experiential learning

One challenge in developing this lesson is the perception that the central concept (i.e., the calculation of a tangent) is simple, can be quickly taught, and is easy to remember. This perception, however, overlooks opportunities for experiential learning that occur infrequently in high school Mathematics. Topics in Mathematics start to become more abstract and contrived over time when represented as worded problems. This activity directly applies mathematical concepts to real-world contexts to engage students in hands-on learning.

Unexpected pedagogical outcomes

When I conducted this activity in the past, I focused exclusively on the mathematical aspect of applying the formula to find the height of an object. However, the hands-on components of the activity presented opportunities for learning beyond the initial scope during the planning stage. The construction of the clinometer itself served as an avenue for students to develop their practical and engineering design skills. For example, in the selection of materials for their clinometer, using thick string like yarn can be difficult to make precise readings using the protractor since the width of the string might span multiple angle markings instead of just one. If a thin string is used, it could be prone to breakage from the mass of the weight even if it can provide a more precise measurement. Another example is the choice of weight used. If it is too light, it can be swayed by the wind and lead to inaccurate readings. In contrast, if it is too heavy, it can make the clinometer difficult to handle. These material and design considerations are valuable learning outcomes that are afforded by integrating Science, Technology, and Engineering Design into the lesson.

Cost and reusability

While the cost of materials was an important consideration, it did not prove to be a barrier for student participation. In addition, I found that disassembling the clinometers allowed the next batch of students to reconstruct them again. This was more engaging for the students as they enjoyed the design and construction aspects of the activity as opposed to using pre-assembled clinometers.

Mr Leo Andrei Crisologo

2.3

Leveraging the Internet of Things to Enhance Hydroponic Systems

Dr Chen Liu Qi & Mdm Rosmiyati Bustami

INSTITUTIONAL PROFILE

Punggol Secondary School

LOCATION
Singapore

TYPE OF INSTITUTION
Public Secondary School

LESSON DETAILS

NUMBER OF LESSONS
4 lessons

DURATION
45–60 mins/ lesson

GRADE LEVEL
Secondary 1 (Grade 7)

SUBJECT/ DISCIPLINE
Geography, Science (Biology), Technology (Coding, Internet of Things, micro:bit)

NO. OF STUDENTS/ PARTICIPANTS
360 (9 classes)

STUDENT READINESS
Mixed ability

Designed as a project-based learning experience to develop students' adaptive thinking skills, the "Smart Growing & Smart Monitoring" project draws on students' theoretical knowledge on urban farming, sustainability, and plant biology (Geography and Science) while cultivating their skills in foundational block programming and hardware assembly (Technology). Centred on Punggol Secondary School's Environmental Sustainability programme, the project addresses the issue of global food security and features at its core, the challenge of building a "smart" hydroponic system from which its produce can be harvested to benefit the local community.

In this chapter, we learn:

- ✓ How the Internet of Things (IoT) can work with micro:bit technology
- ✓ How to code and set up a remote plant growth monitoring device using IoT and micro:bit technology

Environmental sustainability is Punggol Secondary School's signature programme to promote adaptive thinking. In this module, the school partnered with Science Centre Singapore to design lesson packages to teach students about block programming and to create a "smart" hydroponic system for their hydroponic farm.

The project's core focus was to teach students how to monitor plant growth remotely using the Internet of Things (IoT). Students began with basic coding skills using **micro:bit** — an educational tool designed to engage students in software writing and creative projects. Students then grew hydroponic seedlings and used IoT devices to measure plant growth over time. The outputs of this lesson can be used to monitor the growth of plants in soil, and any other medium as well.

Through the IoT system, students tracked plant development remotely, eliminating the need for constant manual measurements. When growth patterns show irregularities, students learned to analyse the data and troubleshoot issues, developing critical and adaptive thinking skills while understanding the advantages and challenges of real-world applications of technology. The project concluded with a social sustainability component, where the harvested produce was donated to a local old folks' home.

Did you know?

STEM Inc is a unit within Science Centre Singapore dedicated to igniting students' passion for STEM. They create unique lessons that complement the local school syllabus through the STEM Applied Learning Programme, which integrates STEM innovations into classrooms.

SCAN TO LEARN
More about STEM Inc

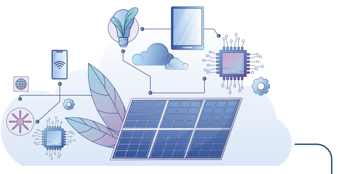
Topics covered in this lesson

Geography	Mathematics
• Understanding urban farming and food security in Singapore • Exploring how sustainable food production supports land-scarce cities • Understanding environmental sustainability and the importance of resource management • Connecting hydroponics, smart technology, and resilient food systems	• Monitoring plant growth data displayed through IoT-generated line graphs • Observing patterns and trends in plant growth • Interpreting simple data visualisations to understand changes in plant growth
Science	**Technology**
• Understanding plant growth and development • Understanding the effect of environmental conditions on plant growth	• Leveraging the IoT to enhance hydroponic systems • Using ultrasonic sensors and micro:bit coding for plant monitoring • Applying smart monitoring technology for urban farming solutions

Understanding IoT & micro:bit

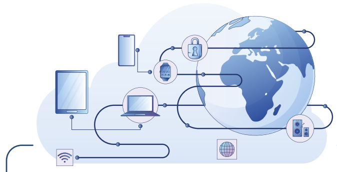
The **Internet of Things (IoT)** refers to a network of physical devices, vehicles, appliances, and other physical objects that are embedded with sensor software and network connectivity, allowing them to connect and share data[1]. IoT devices range from “smart” thermostats, automated vacuum cleaners, and watches, to complex industrial machinery and transportation systems.

There are five key components of IoT technology:



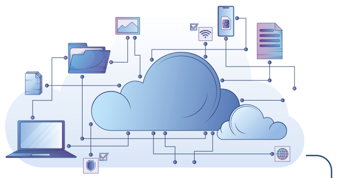
1 **Sensors and actuators**

Allow machines and devices to interact with the real world (e.g., ultrasonic sensors to measure the heights of plants)



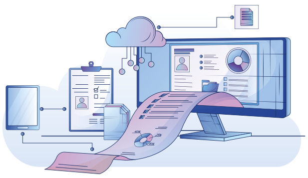
2 **Connectivity technologies**

Transmit IoT data from sensors to the cloud storage (e.g., Wifi and Bluetooth)



3 **Cloud computing**

Stores, processes, and analyses data generated from IoT devices (e.g., on the ThingSpeak platform)



4 **Big data analytics**

Make sense of data generated by IoT devices using data analytics tools such as machine-learning algorithms and data visualisation tools

5 **Security and privacy technologies**

Protect the data generated from IoT devices and ensure they are confidential (e.g., using encryption or password controls)

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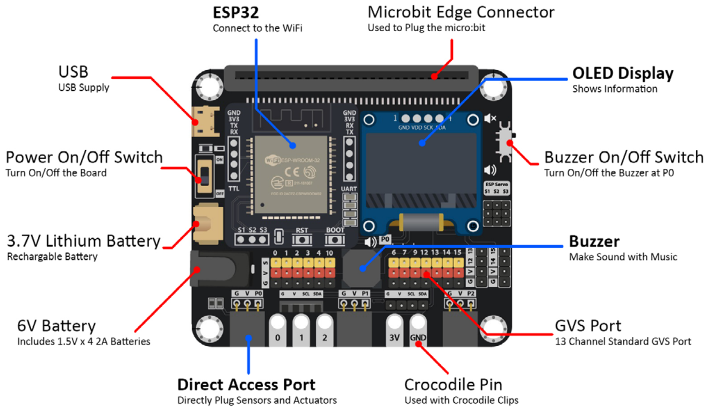
[1] “What is the Internet of Things (IoT)?” IBM. https://www.ibm.com/think/topics/internet-of-things

A **micro:bit** is a pocket-sized computer designed to help children learn basic coding and programming skills. It can be used to create a wide range of computing projects by connecting it to other devices or using its built-in features.

SCAN TO ACCESS
Resources for crafting lessons with the micro:bit



Example of an expansion board for micro:bit

In this lesson, Dr Chen and colleagues from STEM Inc demonstrated how micro:bits can be configured as a microcontroller and used as part of an IoT network that allowed students to remotely monitor plant growth.

SCAN TO LEARN
More about micro:bits and their applications

Citiponics, Singapore’s first urban farm on the rooftop of a multi-storey carpark

Designing an IoT-enabled hydroponics shed in school

Punggol Secondary School’s journey began in 2021 with a traditional Geography investigation on rainforest ecosystems, where Secondary 1 students grew seedlings using different types of soil. To avoid spillage and clean-ups in classrooms, teachers transformed an abandoned greenhouse shed on the school grounds into a basic hydroponics facility. The repurposed shed presented an opportunity for students to appreciate the creative use of space in a land-scarce city like Singapore. In addition, they learnt how a place can be transformed for sustainable purposes, by: (1) studying the interaction between plants and animals and (2) connecting local food production efforts with the nation's broader sustainability goals. The project was recognised with a Ministry of Education Innergy (Bronze) Award in 2022 for its innovative approach to teaching geographical concepts through sustainable farming practices.

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[1] Source: Smarthon Smart City IoT Starter Kit > IoT:bit Introduction, retrieved from https://smarthon-docs-en.readthedocs.io/en/latest/smartcity/2_IOTbit.html

Did you know?

Hydroponics farming is the cultivation of plants with water and nutrients rather than soil. Direct exposure to nutrient-filled water can be a more effective and versatile method of growth than traditional irrigation. As soil is not required, this makes hydroponics a viable option for urban farming and land-scarce contexts.

SCAN TO READ
More about
hydroponics farming

However, the shed needed to be locked for security because the produce grown was being donated to an old folks' home for consumption. This presented teachers with a logistical hurdle as they had to unlock the shed whenever students needed to measure plant growth.

To solve this, Mdm Rosmiyati and colleagues from Punggol Secondary worked with Dr Chen and her team from STEM Inc to use IoT technology to complement the hydroponics farming project, and devised a solution where students could monitor plant growth from their classrooms.

Students entering the hydroponics shed

Produce grown in the hydroponics shed in Punggol Secondary School

Tip

Science Centre Singapore provided Punggol Secondary School with the necessary equipment for the IoT project and coding lessons. Schools can reach out to local technology education providers for hardware resources and professional development support.

Key factors for success:

- Enhance project effectiveness by **integrating it across multiple subject areas** to foster interdisciplinarity.
- **Consistent monitoring** is crucial for both plant growth success and student engagement; regular schedules for data collection and analysis help students develop disciplined approaches to scientific observation, while ensuring optimal plant growth conditions.
- **Community engagement** creates meaningful connections between classroom learning and real-world impact.
- Give students **autonomy to troubleshoot problems** and develop solutions independently to build resilience and confidence and prepare them for real-world challenges.

The project demonstrated how IoT technology can support and contribute to effective monitoring and sustainable urban farming practices. Beyond the acquisition of technical skills, students developed environmental awareness, data literacy, and social responsibility — crucial competencies for future-ready citizens.

Module plan

Smart growing & smart monitoring

Designed specifically for Secondary 1 students, the programme was structured into two main components that work in tandem to deliver a holistic educational experience.

1. Technology (coding)

The first component, conducted over four periods, focused on introducing students to modern technological tools.

Students immersed themselves in hands-on learning about the Internet of Things (IoT), ultrasonic sensors, and micro:bit coding. The learning journey was crafted to achieve three key objectives:

1. Students describe the fundamental features of IoT systems, ultrasonic sensors, and micro:bit technology.
2. Students explore and articulate real-world applications of the technologies.
3. Students explain how the different technologies can be integrated to work together effectively.

2. Science & Geography (hydroponics)

The second component comprised a structured Geography-led hydroponics investigation conducted over four weeks.

Week 1: Students set up their hydroponic seedlings in the school's hydroponics shed and installed the IoT sensors required for monitoring plant growth.

Weeks 2 to 4: Students collected and analysed data remotely from the classroom. IoT-generated graphs from ThingSpeak were used to guide students to interpret patterns and trends.

Week 4: Students confirmed their data-based observations with real-world outcomes when they harvested their plants, reinforcing the value of technology-enabled sustainable agriculture.

These lessons focused on developing students' skills in data interpretation, understanding of growth indicators, and how digital monitoring can be used as part of a sustainable farming practice.

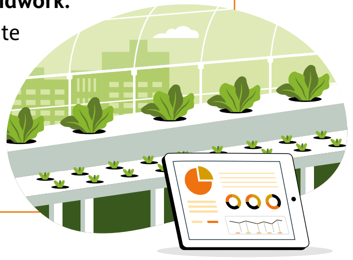
This chapter covers component 1, on designing an IoT setup to enable remote plant growth observation.

i. Desired learning outcomes and objectives

Internet of Things	• Students understand how reflection of sound (in ultrasonic sensors) can be applied to find distances • Students understand and apply basic coding skills using Microsoft MakeCode and micro:bit • Students better appreciate the affordances of IoT microcontrollers (e.g., micro:bit) and electronic sensors (e.g., ultrasonic sensors)
Applications of technology	• Students recognise and appreciate how different parts of the IoT ecosystem can be engineered (adapted and integrated) through coding to develop a solution for an individual or community (from the perspective of an urban farmer)
Calculation and measurement of plant growth	• Students apply basic knowledge on functions to calculate the height of a growing plant using raw data obtained from the IoT setup (i.e., the distance between the plant and ultrasonic sensors)
Values and attitudes	• Students develop an appreciation and concern for the environment through hands-on experience with sustainable farming • Students build a sense of responsibility by contributing to food production and understand the importance of sustainable resource management

Specific instructional objectives

- **Connecting hands-on coding with real-world relevance:** Students describe one way the affordances of IoT can be harnessed with the use of micro:bit, ultrasonic sensors and a Wifi module to help an urban farmer
- **Grounding data collection and analysis in authentic fieldwork:** Students plan and construct a prototype to demonstrate the use of micro:bit with IoT:bit (a breakout board that contains a Wifi module) to send and retrieve data to a cloud-based platform such as ThingSpeak and use it to determine distance



ii. Carrying out the module

This four-lesson module tapped on students' prior knowledge on hydroponics farming (Science) and the geographical concepts of space, place, environment, and scale. The module detailed below focuses on incorporating IoT usage and micro:bit coding to assist with remote monitoring of plant growth.

Unlocking foundatinal knowledge

a. Teacher preparation

Teachers first attended a session on coding with micro:bit where they learned how to:

- Use micro:bit with ultrasonic sensors to measure distance
- Connect micro:bit to IoT with IoT:bit (breakout board with Wifi module) and send data to a cloud-based platform (ThingSpeak)
- Retrieve data from ThingSpeak
- Assemble the devices (micro:bit, ultrasonic sensors, and IoT:bit) together to measure the height of plants

Materials required (per group):

- *1x laptop (Windows preferred) with internet access*
- *1x micro:bit with 1X USB wire for connecting to the laptop*
- *1x Smarthon IoT:bit extension breakout board (or any micro:bit breakout board with an in-built Wifi module)*
- *1x power adapter (for powering IoT:bit with micro:bit)*
- *2x ultrasonic sensors (with 2X connecting wires)*
- *1x retort stand for setting up the IoT:bit (with micro:bit and ultrasonic sensors) for plant height measurement*

SCAN TO SEE

The IoT starter kit used in this lesson

The ultrasonic distance sensor used in this lesson

b. Introducing food security in Singapore

Prior to their lessons on IoT and coding, students were given a lesson on understanding food security in Singapore, contextualising hydroponics farming as an important development in local agribusiness.

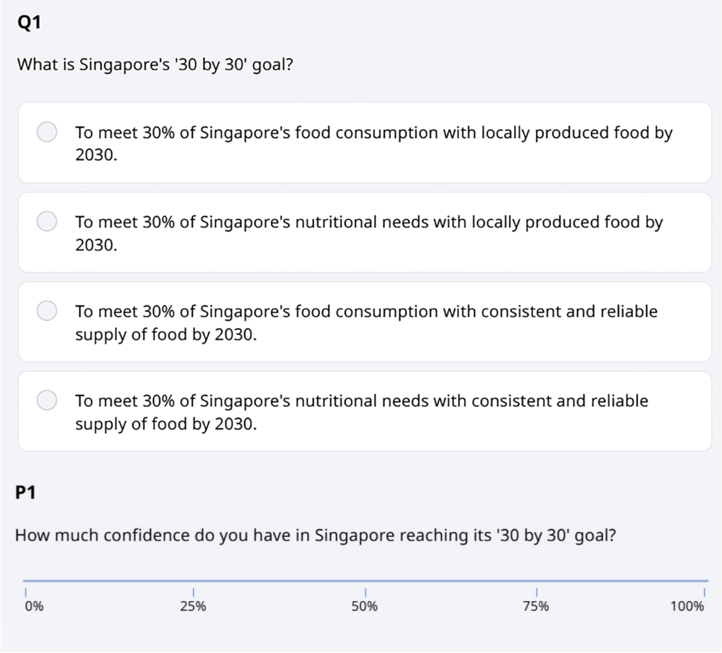
They watched three videos on Singapore's food security concerns and "30 by 30" goals and answered multiple choice questions and a slider poll to check their understanding.

SCAN TO WATCH

How Singapore Does Farming Without Farmland

How to Grow Kratky Hydroponic Lettuce Cheap & Easy

IoT Architecture for Agriculture



Q1

What is Singapore's '30 by 30' goal?

○ To meet 30% of Singapore's food consumption with locally produced food by 2030.

○ To meet 30% of Singapore's nutritional needs with locally produced food by 2030.

○ To meet 30% of Singapore's food consumption with consistent and reliable supply of food by 2030.

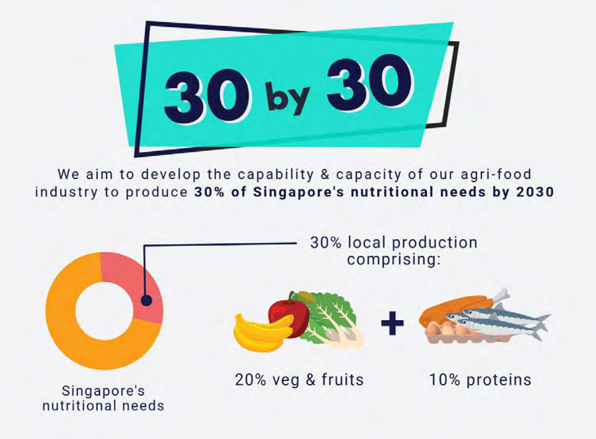
○ To meet 30% of Singapore's nutritional needs with consistent and reliable supply of food by 2030.

P1

How much confidence do you have in Singapore reaching its '30 by 30' goal?

The lesson was followed up with two introductory hydroponics videos, followed by an open-ended question where students listed and justified two essential monitoring factors. This activity served as a bridge to two more videos that detailed the importance of electrical conductivity and pH monitoring.

Lastly, as a lead into the lesson on IoT and micro:bit coding, students considered if (and how) modern technology could monitor and control these variables.



Singapore's 30 by 30 food security goal

SCAN TO WATCH

What is hydroponics?

How to grow plants without soil?

Nutrient solution: how to measure and adjust hydroponics

Water level indicators for hydroponic and sub-irrigated tanks of growing medium

Additional resources

Food for Thought | Hydroponics: Getting to the Root of the Myths (sfa.gov.sg)

Advanced Monitoring in Hydroponics — AGrowTronics — IIoT For Growing

Monitoring Water Levels in Hydroponic Systems: Solutions and Best Practices (rikasensor.com)

Small-scale Hydroponics | UMN Extension

Lesson 1

Introduction to IoT, ultrasonic sensors, and micro:bit

The aim of this lesson was to introduce IoT and ultrasonic sensors as devices used in the project.

At the end of this segment, students should be able to:

- Describe the basic features of IoT, ultrasonic sensors, and micro:bit.
- State the applications of IoT, ultrasonic sensors, and micro:bit.

Watching introductory videos and understanding keywords

This lesson utilised the Singapore Ministry of Education's **Student Learning Space (SLS)**, an online learning platform designed to promote independent learning and equip teachers with a wide range of resources to support their lessons. The platform has features like polls and Interactive Thinking Tools (ITT). Co-developed by STEM Inc and Punggol Secondary School, the lesson used a blended approach where some tasks were assigned as homework (e.g., "Understanding what IoT is") and others as in-class self-directed tasks (e.g., coding via stepwise video instructions), with peer engagement facilitated by teachers. While the lesson materials were tailored to meet the needs of Punggol Secondary School, the materials are available in the Community Gallery for schools across Singapore to access.

Students began the lesson with three videos providing a beginner's introduction to the IoT, ultrasonic sensors, and micro:bit. You may choose to show these videos in class or assign them as homework before the lesson.

SCAN TO WATCH

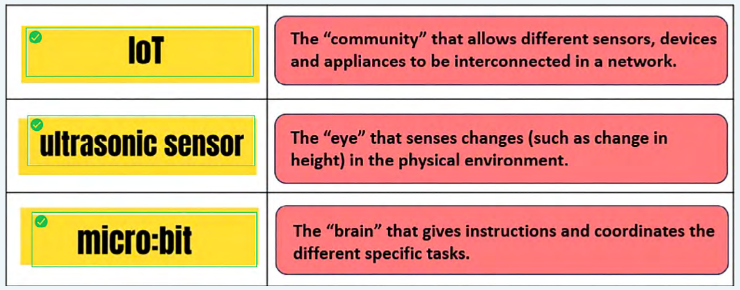
IoT explained in 6 minutes

The basics of ultrasonic sensors

Introducing the BBC micro:bit

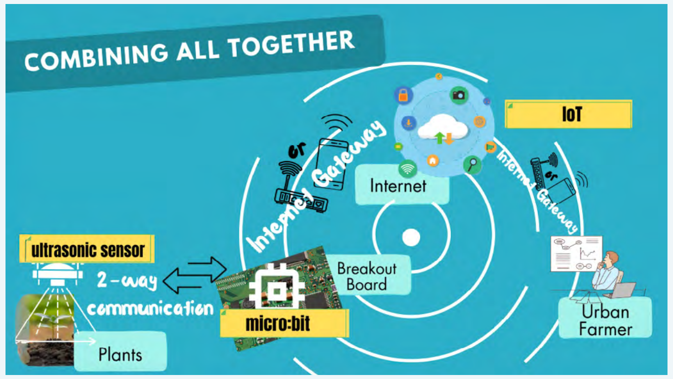
Next, a short keyword and definition matching activity was given to test their knowledge and understanding of the relationship between the ultrasonic sensor as the "eye", the micro:bit minicomputer as the "brain", and the IoT network of devices as a "community".

Q1: Match the keywords by placing them boxes in the left column and the correct definition in the right column.



IoT	The "community" that allows different sensors, devices and appliances to be interconnected in a network.
ultrasonic sensor	The "eye" that senses changes (such as change in height) in the physical environment.
micro:bit	The "brain" that gives instructions and coordinates the different specific tasks.

Q2: Match the keywords to the correct options in the image.



Pedagogical considerations

Students may already be using IoT in their daily lives without knowing it, such as using a robotic vacuum cleaner. Ultrasonic sensors on the other hand have been used for a long time in a multitude of applications, such as in ultrasound scans or sonars. The introductory videos help establish baseline knowledge while eliciting any prior knowledge on the subject.

Lesson 2
Creating an account in "the cloud"

This lesson focused on using ThingSpeak, an analytics cloud platform that can receive and analyse data collected from an IoT project.

At the end of this lesson, students should be able to:

- Register for a MathWorks account to use ThingSpeak
- Create a new channel in ThingSpeak and obtain a unique Application Programming Interface (API) key for the channel

ThingSpeak for IoT Projects

Data collection in the cloud with advanced data analysis using MATLAB

a. Creating a ThingSpeak account and unique channel to monitor plant growth

Here, students learned key vocabulary (such as ThingSpeak, cloud computing, and analytics) through hover-over definitions on student learning space (SLS) to better understand the tools and processes they were engaging with.

IoT makes extensive use of cloud computing. An analytics cloud platform service, such as ThingSpeak, allows you to collect and analyse data easily.

One ThingSpeak account was created for each student group before students were guided to create a unique channel for their plant growth monitoring project.

Steps:
1. Go to https://thingspeak.com/, register an account and login.
2. Click "**Get Started for Free**"
3. Enter your email and click "**Create one!**"
4. Follow the steps to create an account
5. To complete your MathWorks Account setup, in your email message, click "**Verify email**".

Congratulations. You have successfully created a MathWorks account in ThingSpeak! 👏 🎉

Now that you have a MathWorks account in ThingSpeak, let's create a channel and get the API Key. **The API Key will be important for your coding later.**

Steps:
1. Log into your MathWorks account in ThingSpeak.
2. Click on Channels > My Channels > New Channel
3. Under the category "**Name**", input your channel in the following format - **Class_Group Number** (e.g. 1B_2 for Class 1B Group 2).
4. Check the boxes for "**Field 1**" and "**Field 2**". You can name your sensors as "**distance sensor 1**" and "**distance sensor 2**" or leave them as they are.
5. Click "**Save Channel**" to save your channel.
6. Select "**API Keys**" tab from the channel you have just created. Copy the API Key. *Select the API Key and press* ***ctrl + c*** *to copy the API key. You will need this API key in section C6.*

This API Key is unique to your group's channel. The micro:bit will only send data to your channel with his unique key.

To close the lesson, the teacher recapped what they had learned and shared the next steps.

Tips

- To prevent students from forgetting or losing their team's MathWorks account details, students should record their details (username, password, and API) on an accessible platform.
- To free up classroom time, a platform such as the SLS can be used to facilitate a flipped classroom approach. Teachers can share resources such as videos and tasks and assign them as homework. Class time can then be reserved for hands-on activities, discussion (e.g., after collectively watching a video as a class) and/or to highlight selected parts to students.

Lesson 3
Starting their first IoT project

This lesson focused on assembling the components for their plant growth measuring system to create a means of remotely measuring plant growth.

At the end of this lesson, students should be able to:

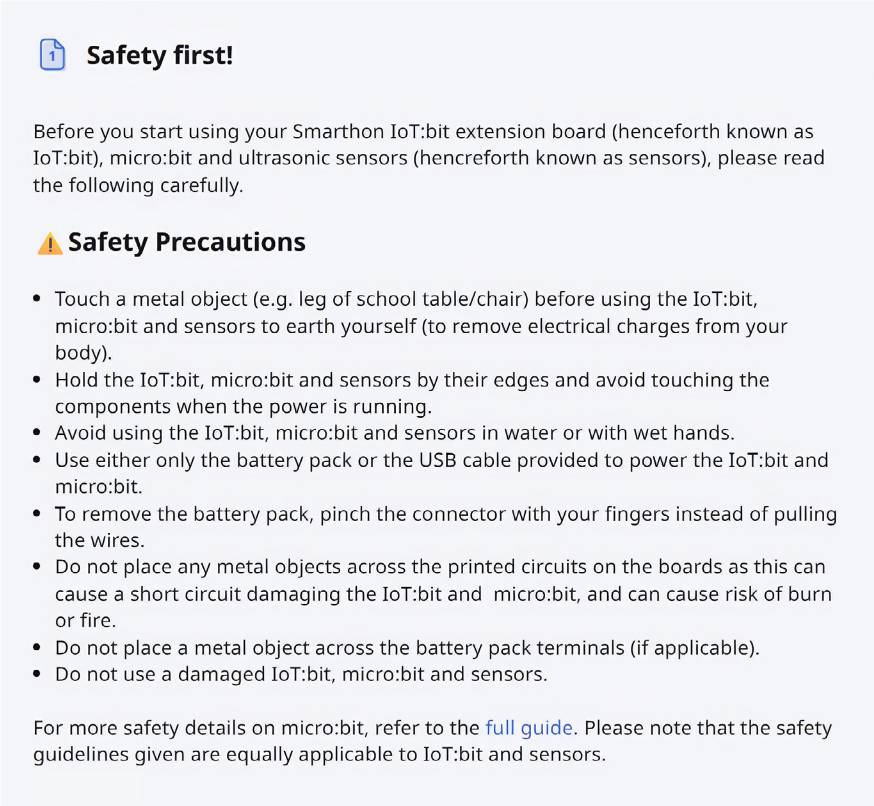
- Identify the basic components of the Smarthon IoT:bit
- Successfully assemble the plant growth measuring system (i.e., micro:bit, ultrasonic sensors, and the IoT:bit)
- Successfully collect data from the ultrasonic distance sensors
- Connect the micro:bit to Wifi
- Programme the micro:bit to upload data to ThingSpeak

a. Safety precautions

Students were first briefed on the necessary safety precautions before beginning the lesson.

Pedagogical considerations

Dr Chen, Mdm Rosmiyati, and team developed short (under one minute) instructional videos to accommodate student profiles favouring bite-sized content.



Safety first!

Before you start using your Smarthon IoT:bit extension board (henceforth known as IoT:bit), micro:bit and ultrasonic sensors (hencreforth known as sensors), please read the following carefully.

⚠ Safety Precautions

- Touch a metal object (e.g. leg of school table/chair) before using the IoT:bit, micro:bit and sensors to earth yourself (to remove electrical charges from your body).
- Hold the IoT:bit, micro:bit and sensors by their edges and avoid touching the components when the power is running.
- Avoid using the IoT:bit, micro:bit and sensors in water or with wet hands.
- Use either only the battery pack or the USB cable provided to power the IoT:bit and micro:bit.
- To remove the battery pack, pinch the connector with your fingers instead of pulling the wires.
- Do not place any metal objects across the printed circuits on the boards as this can cause a short circuit damaging the IoT:bit and micro:bit, and can cause risk of burn or fire.
- Do not place a metal object across the battery pack terminals (if applicable).
- Do not use a damaged IoT:bit, micro:bit and sensors.

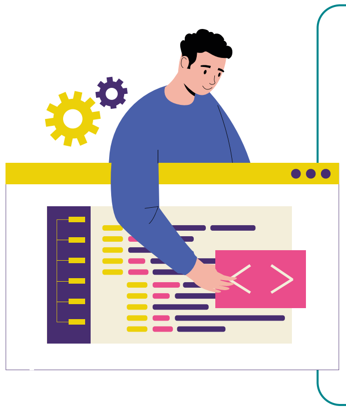
For more safety details on micro:bit, refer to the full guide. Please note that the safety guidelines given are equally applicable to IoT:bit and sensors.

b. Hardware assembly

Here, a video guided students to assemble the micro:bit and ultrasonic sensors onto the IoT:bit expansion board. This expansion board enables connection of different sensors without welding and Wifi capability.

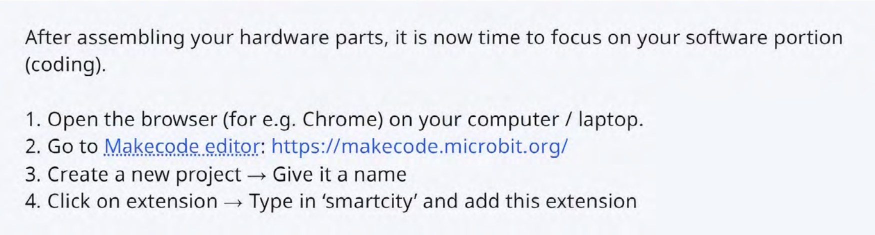
c. Adding the MakeCode extension onto their browser

As some block codes specific to IoT and ultrasonic sensors are found on a separate block extension, these need to be added as an extension. For this project, Dr Chen and team used MakeCode, a free web-based platform for code creation using the block editor or text editor.



Tips

- Make sure the orientation of the pin is correct when plugging it in. The pins are colour-coded and should be connected black to black (ground) and yellow to yellow (signal)
- Students may find difficulties connecting to the network, and having a reliable Wifi network is important (refer to the troubleshoot checklist in section E for more help)



After assembling your hardware parts, it is now time to focus on your software portion (coding).

1. Open the browser (for e.g. Chrome) on your computer / laptop.
2. Go to Makecode editor: https://makecode.microbit.org/
3. Create a new project → Give it a name
4. Click on extension → Type in 'smartcity' and add this extension

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Pedagogical considerations

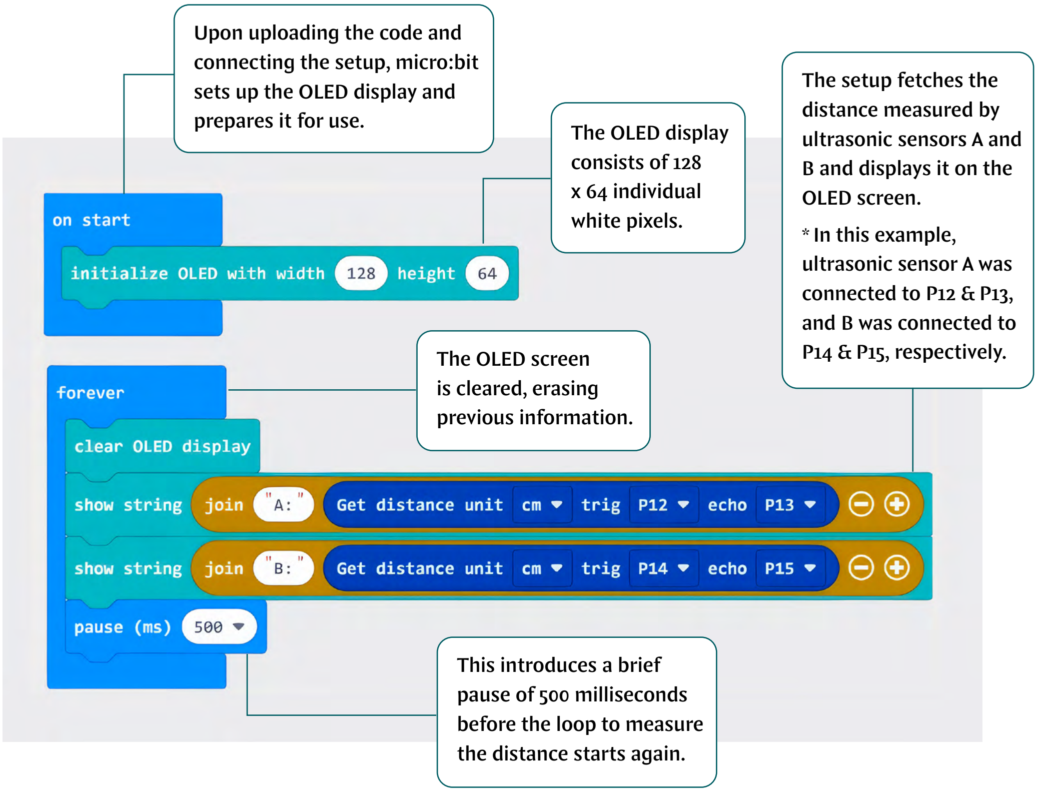
In addition to short videos on coding, Dr Chen's team also provided screenshots of the instructions and the model code to further support differentiated instruction.

---

d. Measuring distance with the ultrasonic sensors

Next, students connected their setup via the USB cable and coded their setup with a video tutorial and guidance from the screenshot provided below. They tested the accuracy of their results by comparing them with manual ruler measurements.

Students exploring block programming for Smart Hydroponic System



```
on start
    initialize OLED with width 128 height 64
forever
    clear OLED display
    show string join "A:" Get distance unit cm trig P12 echo P13
    show string join "B:" Get distance unit cm trig P14 echo P15
    pause (ms) 500
```

Upon uploading the code and connecting the setup, micro:bit sets up the OLED display and prepares it for use.

The OLED display consists of 128 x 64 individual white pixels.

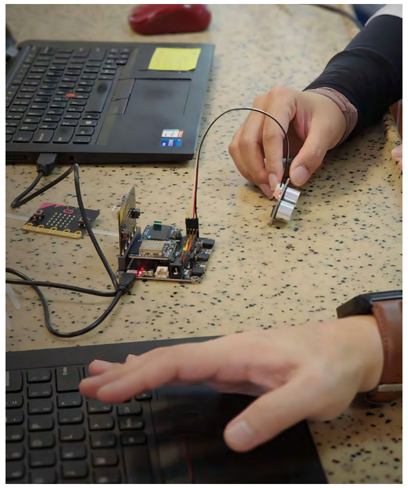
The setup fetches the distance measured by ultrasonic sensors A and B and displays it on the OLED screen.

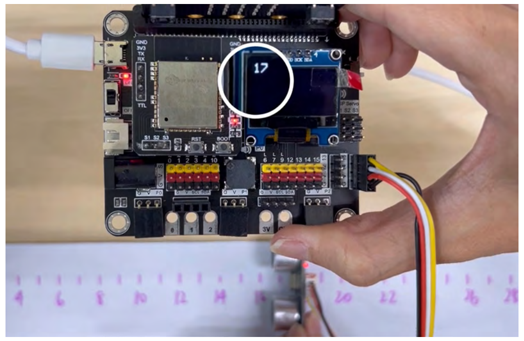
* In this example, ultrasonic sensor A was connected to P12 & P13, and B was connected to P14 & P15, respectively.

The OLED screen is cleared, erasing previous information.

This introduces a brief pause of 500 milliseconds before the loop to measure the distance starts again.

Code to measure the distance between ultrasonic sensors A & B
Code extension: Smartcity





(left) Students setting up their micro:bit

(top) Students manually checking the distance between ultrasonic sensors

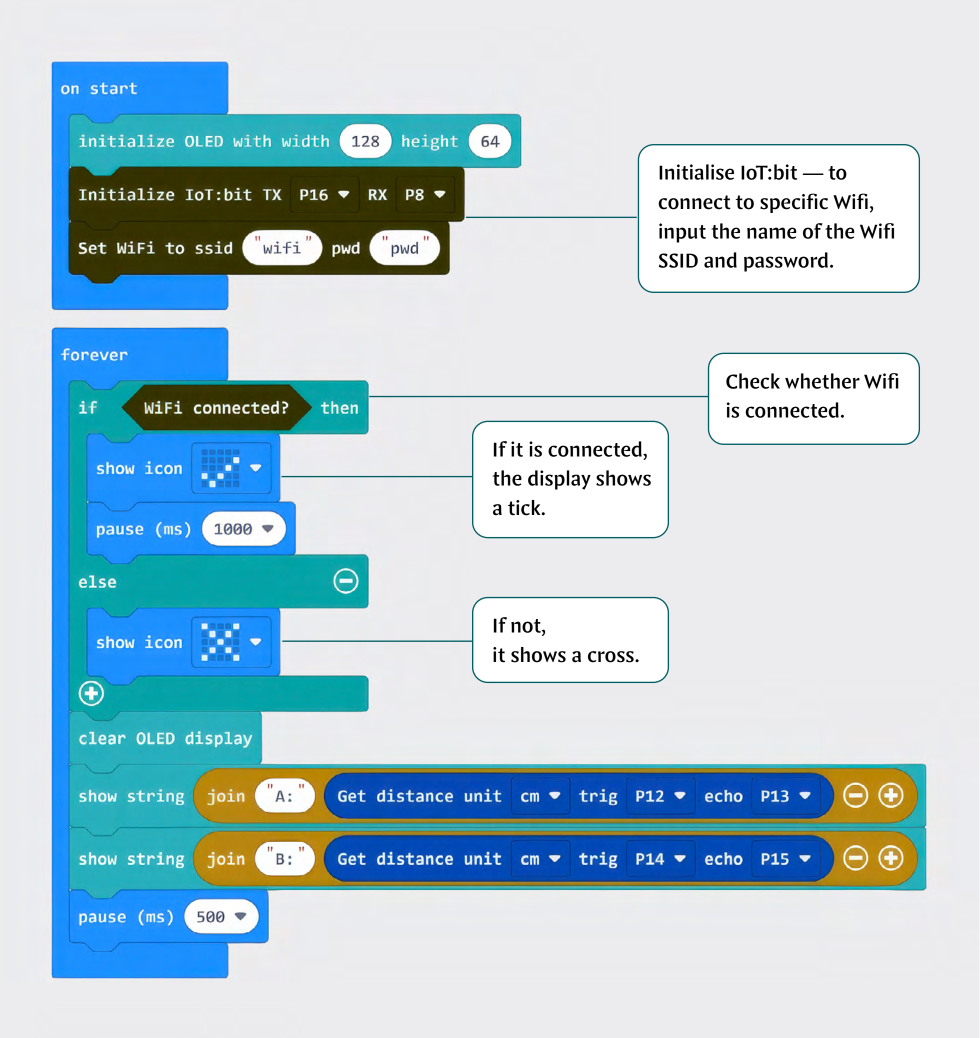
At the end of this segment, students assessed their confidence level in the setup and coding process through a poll. Options in the poll included, "I am very confident with the setup and coding!" and "Help me! I don't know what is going on!"

e. Connecting to the internet

To code and connect the setup to the internet, enabling the data to be uploaded and retrieved from ThingSpeak, students were guided by a video and the screenshot provided below.

Tips

- Please ensure there is a Wifi 2.4GHz signal available in your area. 5GHz is not supported. You will also need the Wifi name and password.
- You may wish to remind students to replace "Wifi" and "pwd" in the downloaded code with the appropriate Wifi details.



```
on start
    initialize OLED with width 128 height 64
    Initialize IoT:bit TX P16 RX P8
    Set WiFi to ssid "wifi" pwd "pwd"
forever
    if WiFi connected? then
        show icon
        pause (ms) 1000
    else
        show icon
    clear OLED display
    show string join "A:" Get distance unit cm trig P12 echo P13
    show string join "B:" Get distance unit cm trig P14 echo P15
    pause (ms) 500
```

Initialise IoT:bit — to connect to specific Wifi, input the name of the Wifi SSID and password.

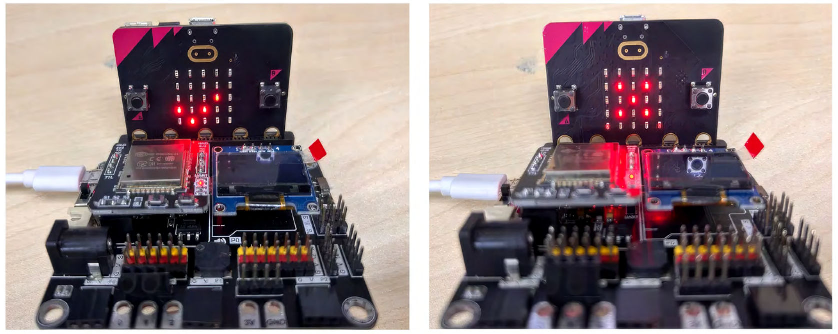
Check whether Wifi is connected.

If it is connected, the display shows a tick.

If not, it shows a cross.

Code to connect setup to Wifi and measure the distance between sensors
Code extension: Smartcity

Students then checked the Wifi connection status on the micro:bit LED display (a tick indicated success, while a cross indicated failure to connect).



Setups showing that the micro:bit connected (left) and failed to connect (right) to the Wifi

To encourage students to work more independently, a troubleshooting guide was provided.

4. Troubleshooting

If you encounter issues with the WiFi connection, consider the following troubleshooting steps:

1. Check the proximity to the WiFi hotspot. Ensure that the hotspot is within a reasonable distance for a stable connection.
2. Check the SSID (WiFi name) and password for any typo errors.
3. Ensure that the USB power is connected correctly.
4. Confirm that you are using a 2.4 GHz frequency WiFi channel.
5. Follow the best practice ☰ on using IoT:bit.

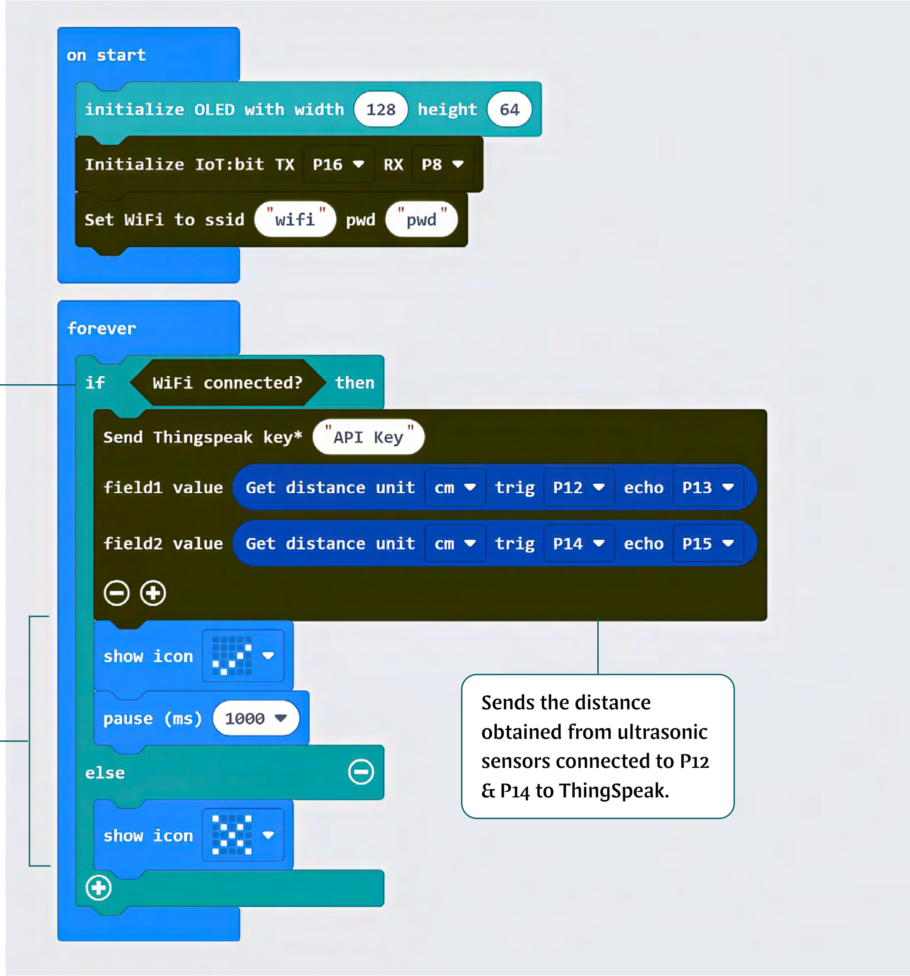
Before advancing to the next section, it's essential to secure a reliable WiFi connection for seamless integration with ThingSpeak in upcoming activities.

This segment concluded with a poll on students' learning experience, with options such as "I managed to connect the micro:bit to the Wifi!" and "I did not manage to connect the micro:bit to the Wifi at first but managed after troubleshooting".

f. Final steps

Before proceeding, access to a Wifi 2.4GHz signal (as 5GHz is not supported), the Wifi name, password, and their API key, and a troubleshooting guide were provided.

Students then completed their setup by following a video and screenshot guide to code and establish a ThingSpeak connection.



```
on start
  initialize OLED with width 128 height 64
  Initialize IoT:bit TX P16 RX P8
  Set WiFi to ssid "wifi" pwd "pwd"

forever
  if WiFi connected? then
    Send Thingspeak key* "API Key"
      field1 value Get distance unit cm trig P12 echo P13
      field2 value Get distance unit cm trig P14 echo P15
    show icon
    pause (ms) 1000
  else
    show icon
```

If Wifi is connected, connect to ThingSpeak. Input the API key of your ThingSpeak channel.

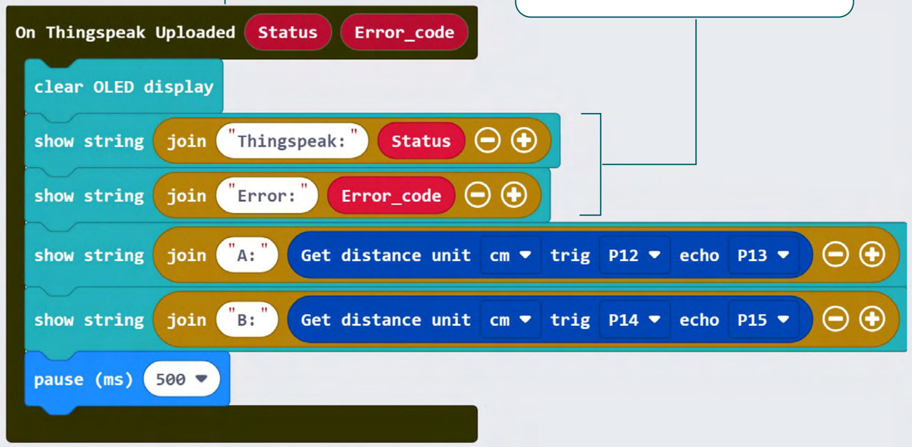
A tick indicates data has been successfully sent; a cross if it has not.

Sends the distance obtained from ultrasonic sensors connected to P12 & P14 to ThingSpeak.

Code to include connection to ThingSpeak & troubleshooting indicators
Code extension: Smartcity

To facilitate the troubleshooting process, display valuable information on the OLED screen. This can include:

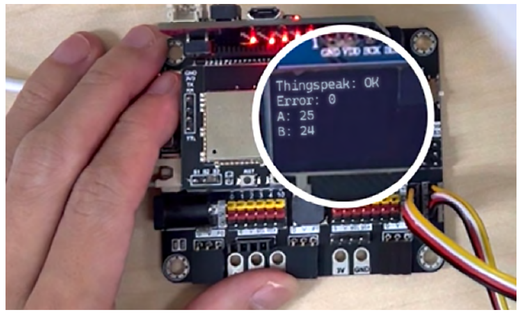
1. ThingSpeak status
2. Error codes in case of Wifi disruption



```
On Thingspeak Uploaded  Status  Error_code
  clear OLED display
  show string  join  "Thingspeak:"  Status
  show string  join  "Error:"  Error_code
  show string  join  "A:"  Get distance unit  cm  trig  P12  echo  P13
  show string  join  "B:"  Get distance unit  cm  trig  P14  echo  P15
  pause (ms)  500
```

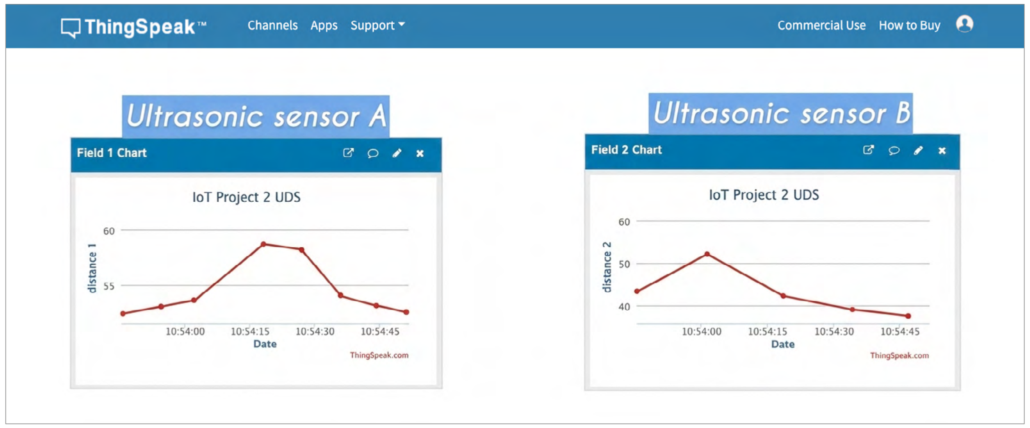
ThingSpeak real-time distance measures are obtained from 2 ultrasonic sensors.

By checking the OLED screen, students were able to verify their ThingSpeak connection and the distance being measured by the ultrasonic sensors. Students also observed their data being uploaded to their ThingSpeak account through real-time graph updates.

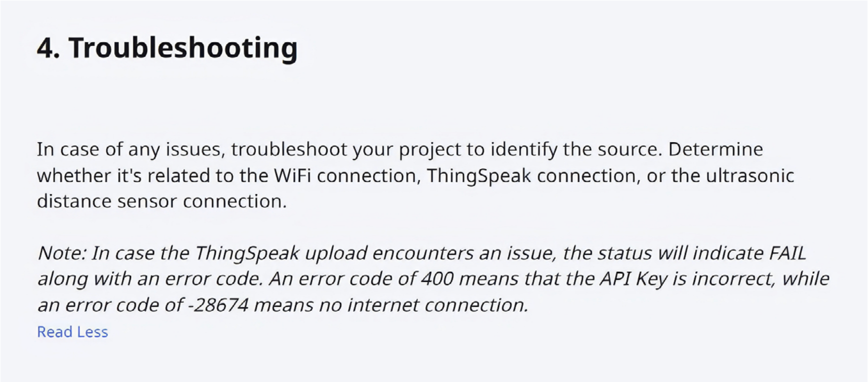


```
Thingspeak: OK
Error: 0
A: 25
B: 24
```

LCD screen showing ThingSpeak connection status and distance measured by the ultrasonic sensors



ThingSpeak charts showing data collected by the setup



4. Troubleshooting

In case of any issues, troubleshoot your project to identify the source. Determine whether it's related to the WiFi connection, ThingSpeak connection, or the ultrasonic distance sensor connection.

Note: In case the ThingSpeak upload encounters an issue, the status will indicate FAIL along with an error code. An error code of 400 means that the API Key is incorrect, while an error code of -28674 means no internet connection.

Read Less

Students then learned to export their data as a CSV file via a short video before completing a progress poll, selecting from options such as “I successfully setup and coded this project!” and “I do not know what went wrong”.

Lesson 4
Possible set-ups for your IoT project

In this last segment, students were guided to set up their equipment to measure plant growth in the hydroponics shed.

Tips

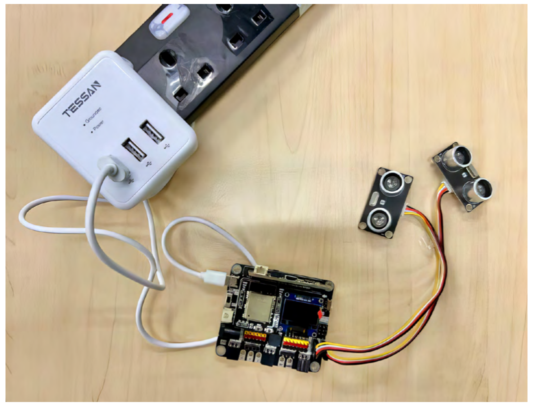
- The IoT breakout board requires a steady power supply (i.e., an electrical outlet is recommended) as the micro:bit and IoT device may enter sleep mode and disconnect from the Wifi when batteries are used.
- Waterproof the set-up with clear plastic to protect the devices from getting wet.

Upon successfully programming their setup, students unplugged the USB cable from their computer/laptop and connected it to a USB adapter (or charger), making the setup portable.

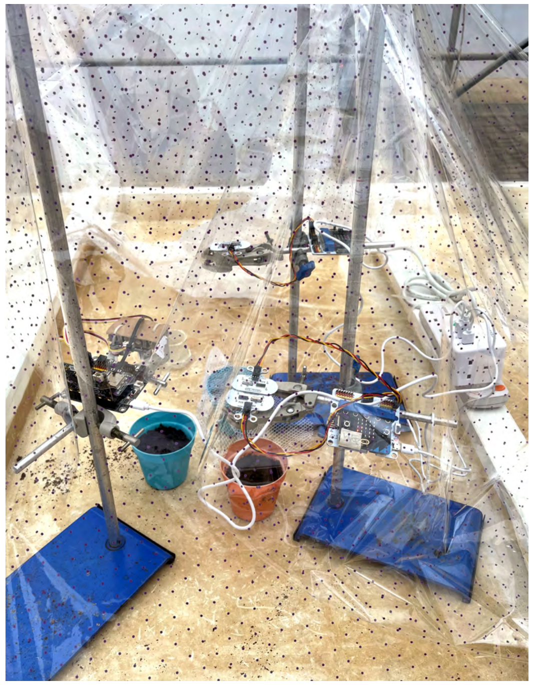
Tips

- Avoid fast-charging USB adapters and chargers to prevent overheating and damaging the components.
- If the school Wifi network is incompatible, use a mobile Wifi device for continuous data collection.

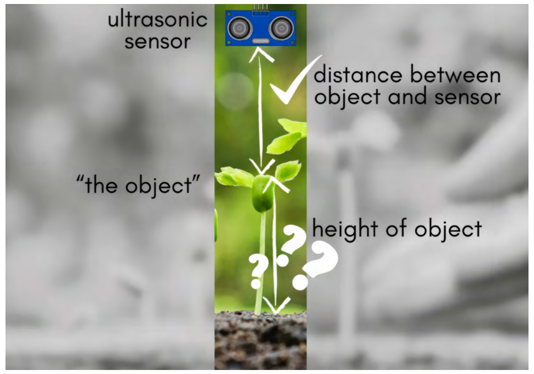
The setup's portability enabled students to experiment with measuring plant height in various ways in the outdoor shed.



Portable setup for measuring height of growing plants



A group's experimental setup



How students calculated the true height of their plants

After troubleshooting their experimental setup, students collected and downloaded their data remotely from ThingSpeak. They subtracted the distance between the plant and the sensors, from the height at which the ultrasonic sensors were placed, to obtain the plant's true height.

Teacher helping students in their experimental setup

Students concluded the project by discussing and sharing their solutions to the following questions:

- How can we adapt the use of the ultrasonic sensor to measure the height of an object? (You may draw diagrams and write down any mathematical equations to share your solution.)
- Now that you've gained insights into IoT functionality and application, what other IoT project are you eager to explore in school? Plan a possible setup and include the apparatus and any materials that are needed. You may sketch diagrams to illustrate your setup.

iii. Challenges and solutions in lesson implementation

Challenge	Possible solution
1. Teacher preparation and training Teacher training involved an hour-long workshop introducing micro:bit coding and the SLS lessons co-created by STEM-Inc. However, some teachers lacked confidence due to insufficient time to become comfortable with the new technology.	Longer, slower-paced training sessions with scaffolded support should be implemented for teachers new to micro:bit and coding technology. One hour is likely sufficient for teachers who have coding experience.
2. Technical difficulties during Science coding lessons Due to incompatibility with the school's Wifi, a private Wifi rental costing S$50/month was needed. However, intermittent connectivity failures required lab staff to test multiple micro:bits causing lesson delays.	Consider local data logging options such as an SD card to store the data collected. This eliminates the need for continuous Wifi. The data can be transferred to ThingSpeak when the 2.4GHz network is available.
3. Geography lesson time constraints The four-period lesson was insufficient for students to fully set up the hydroponic systems and IoT devices and also plant and grow their seedlings.	As seeds and seedlings take time to germinate and grow, respectively, you may wish to kickstart the plant-growing process in the first lesson. This may motivate them to further engage with the lessons that follow.

Authors' reflections

This project integrates STEM to promote educational transformation with the incorporation of smart technology into the school-to-community ecosystem. By tapping on the IoT, time spent on logistics (e.g., managing the hydroponics shed and assisting students with manual measurements) was reduced by 30%, freeing time to focus on improving student outcomes and fostering socially responsible future-ready students through sustainable practices.

Dr Chen Liu Qi & Mdm Rosmiyati Bustami

2.4

The STEM Garden Project for Rural Malaysian Schools

Assistant Professor Dr Norazsida Ramli
& Professor Emeritus Dato' Dr Noraini Idris

INSTITUTIONAL PROFILE

SMK Sungai Lembing

LOCATION
Pahang, Malaysia

TYPE OF INSTITUTION
Rural government secondary school

LESSON DETAILS

NUMBER OF LESSONS
1 lesson

DURATION
420 mins (7 hours)/ lesson

GRADE LEVEL
Form 1 (aged 13)

SUBJECT/ DISCIPLINE
Science (Biology, Agriculture), Technology Design, Mathematics

NO. OF STUDENTS/ PARTICIPANTS
82 (entire cohort together)

STUDENT READINESS
Mixed ability

Planning and developing school gardens can be an economical and practical teaching tool, particularly for rural school environments. In this eight-part single-day lesson, Assistant Professor Dr Norazsida Ramli & Professor Emeritus Dato' Dr Noraini Idris illustrate how designing and growing school gardens can integrate knowledge on Biology, Agriculture, and Technology Design to foster real-world connections to environmental stewardship and encourage open-mindedness to agriculture as a viable and modern career pathway. Teachers from the various subjects of Science, Mathematics, and Technology Design came together in this cohort-wide lesson to facilitate the various activities.

In this chapter, we learn:

- ✓ How a lesson is designed using the RITE STEM framework
- ✓ The advantages of designing a single day STEM lesson
- ✓ How a school garden can be used as a practical tool to introduce project-based STEM learning in low-resourced contexts
- ✓ How designing a school STEM garden can be scaffolded to reinforce and apply students' learning through scientific investigation, a gallery walk, and journal reflection
- ✓ How to adapt the lesson for implementation during regular class time

SMK Sungai Lembing is a rural secondary school in Pahang, Malaysia where more than 80% of the students come from low-income families. As many of these families work as gardeners or small-scale farmers, anchoring this lesson in agriculture — a familiar and meaningful aspect of the students' daily lives — enabled students to better connect and appreciate how STEM contributes not only to their daily lives, but also to the overall sustainability of their own communities through agricultural development.

Assistant Professor Dr Norazsida Ramli & Professor Emeritus Dato' Dr Noraini Idris used the RITE STEM Framework to design a hands-on lesson for rural secondary schools in Malaysia. Through this lesson, students became more observant of the plants around them and drew links between the essential needs of plants such as sunlight, water, carbon dioxide, and nutrients; and scientific concepts such as photosynthesis and plant reproduction. As students tended to come from farming and gardening families, this allowed them to extend their learning beyond the classroom and into their homes, providing opportunities to reinforce their understanding through everyday activities.

Additionally, this lesson served as an economical and practical teaching tool for rural schools with limited resources. To nurture scientific understanding, curiosity, and creativity through experiential learning in a cost-effective, impactful way, the lesson encouraged the use of materials readily available in students' surroundings with minimal addition of other equipment. The lesson is mapped to specific chapters in the Malaysian curriculum.

Topics covered in this lesson		
Science	Mathematics	Technology Design
Relationship of plants with air and gasses *(Form 1, Chapter 7)* Photosynthesis *(Form 1, Chapter 2)* Plant reproduction *(Form 1, Chapter 4)*	Basic polygons *(Form 1, Chapter 9)* Perimeter and area *(Form 1, Chapter 10)*	Design project management *(Form 1, Chapter 2)* Pictorial sketching *(Form 1, Chapter 3)*

In this lesson, students designed a STEM garden, an activity that integrated learning outcomes from the Malaysian national curriculum for the subjects of Science, Mathematics, and Technology Design. Students investigated scientific questions, such as ***"What are the important needs of plants?"*** and ***"Why is sunlight important for plants?"*** These incorporated mathematical thinking, such as determining the shape and area of the garden, and the number of plants that could be optimally placed within the available space. The students collaboratively made informed design decisions on the most suitable plants to grow and the ideal design and location for the garden. In doing so, they were encouraged to connect knowledge across the disciplines of Science, Mathematics, and Technology Design while cultivating values of environmental stewardship, and skills for teamwork and problem-solving.

A one-day, project-based STEM lesson

This lesson was implemented as a full-day activity in a rural secondary school to ensure that students experience project-based learning (PBL) as a continuous and connected process. As the activities are built upon one another, students were able to relate the knowledge and skills acquired from earlier tasks to the later ones. Conducting the lesson within a single day also helped maintain the students' flow of inquiry, allowing them to build momentum and become emotionally invested as they engaged in a high level of cognitive focus to solve a real-world problem.

Additionally, in rural school settings, where access to digital tools, laboratories, or equipment may be limited, a full-day format provides a practical platform for an immersive learning experience. It allows students to complete the hands-on, discussion, and reflection components without interruptions or scheduling conflicts that can occur when planning multiple STEM lessons across the school term. If time permits, schools wishing to conduct the lesson over multiple days should take note that the sequence of activities must be maintained to preserve the logical flow and knowledge progression intended by the lesson's design.

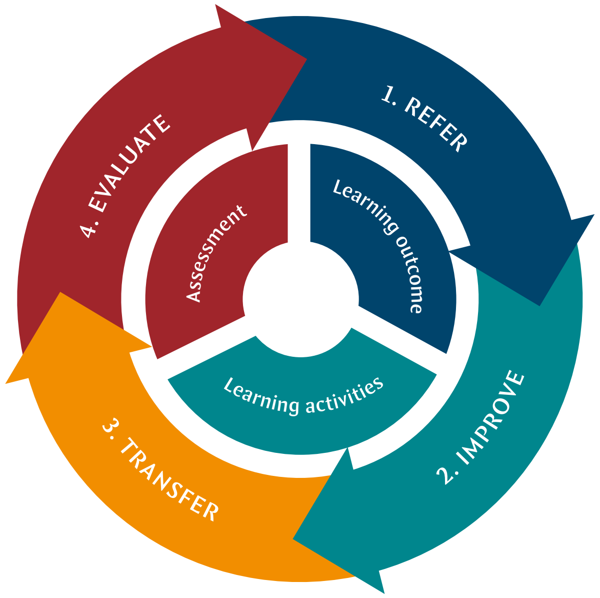
Designing a lesson using the RITE STEM Framework

The teaching and learning activities in this lesson were constructed according to the Malaysian Professional Development RITE STEM Framework. This framework was developed by the Malaysian Professional Development team, led by Professor Emeritus Dato' Dr Noraini Idris, who was appointed to support the Southeast Asian Teacher Education Programme (SEA-TEP).

SCAN TO LEARN
More about the SEA-TEP programme

Read more about the SEAMEO-STEM learning framework for fostering 21st-century skills in teacher education in chapter 1.2!

The RITE STEM Framework serves as a structured guide to support Malaysian teachers in designing lesson plans that integrate scientific reasoning, inquiry-based learning, and cross-disciplinary applications that are aligned with the Malaysian Curriculum Standards. In this project, the framework was used to provide a scalable model for teacher professional development in STEM education, introducing teachers to Disciplinary Core Ideas, the Claim-Evidence-Reasoning (CER) framework, and 3D modelling.



The RITE STEM Framework

Four key phases are noted in the RITE STEM Framework:

1. REFER

The process starts by referring to curriculum standards, current issues, and community contexts to establish a relevant foundation for STEM learning.

2. IMPROVE

Next, the learning outcomes, teaching strategies, and assessment methods are refined by leveraging on the integration of pedagogical models such as the Learning Triangle, 3D Learning, and the Claim-Evidence-Reasoning (CER) Framework to construct the lesson plan.

3. TRANSFER

The refined lesson is then implemented and delivered to students with a focus on ensuring active engagement during their learning experience.

4. EVALUATE

Following lesson enactment, the lesson plan, learning outcomes, and instructional strategies are evaluated, fostering an iterative process of continuous refinement and reflection.

School gardens for STEM education in low-resourced contexts in Malaysia

School gardens are a comprehensive hands-on learning tool for teaching integrated STEM topics at the primary and secondary level. Educational outcomes stemming from creating a school garden range from deepening understanding of plant-based biology and agriculture, to connecting with national food security concerns and cultivating 21st-century skills.

In this lesson, students gained early exposure to agri-tech concepts, sustainable farming practices, and entrepreneurial thinking, equipping them with the skills to envision agriculture as a viable and modern career pathway rather than a traditional livelihood. This approach empowered students to recognise the economic potential of STEM applications in agriculture and encouraged them to innovate within their local contexts.

By designing and planting their own STEM garden in school, students:

•

Understood the importance of plants in sustaining life and maintaining the balance in the ecosystem

••

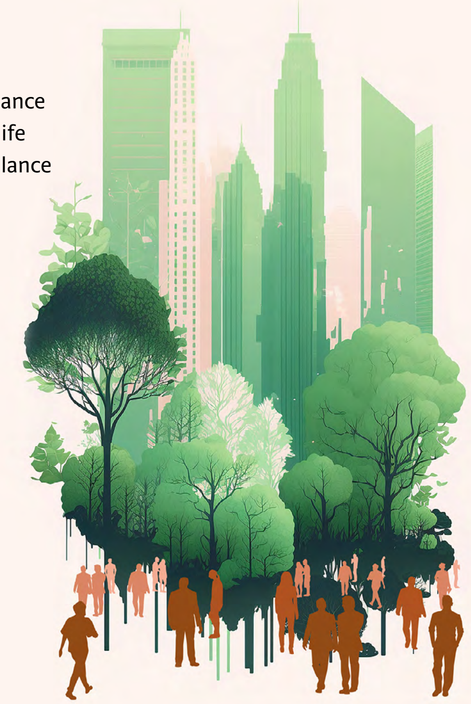
Understood the challenges of urbanisation and limited green spaces (especially in school environments) in Malaysia, and the need for creative gardening solutions

•••

Gained insight(s) into real-world challenges that STEM knowledge can help address, such as food security, sustainability, and climate resilience

••••

Applied their classroom knowledge in a meaningful way that can impact their community



Lesson plan

Designing and planting a STEM school garden

i. Desired learning outcomes and objectives

Desired learning outcomes	Rationale
1. Students identify and explain the basic needs of plants (i.e., water, air, nutrients, and sunlight), and the effects of their absence and their importance for growth.	This helps students build an appreciation for how life systems depend on essential resources and make sense of why plants thrive or die under changing environments.
2. Students explain the role of sunlight in photosynthesis and determine the best location in school that receives optimal sunlight for their STEM garden.	This helps students connect the abstract process of photosynthesis to real-world implications and decisions (such as the importance of finding the optimal gardening location for plant growth).
3. Students classify different types of plants and justify their plant choices for the STEM garden based on reproduction methods and environmental factors.	Students apply the scientific process skill of classification, fostering their understanding of relationships between different scientific phenomena (e.g., plant type, suitability, and environmental factors) and real-world decision-making for their STEM garden.
4. Students integrate knowledge of Science and Mathematics to propose a practical and sustainable design plan for their STEM garden.	Interdisciplinary integration mirrors how real-world STEM problems are solved — not by isolated subjects but through connected knowledge.
5. Students collaborate in groups to present their garden plan and defend their decisions using scientific reasoning and mathematical evidence.	Communication and teamwork are critical 21st-century competencies. Defending ideas with evidence-based reasoning strengthens students' critical thinking skills and provides an avenue to nurture confidence in public speaking.
6. Students demonstrate awareness of environmental stewardship by reflecting on sustainable practices.	Instilling values of stewardship connects learning to moral responsibility and prepares students to be environmentally conscious citizens. Anchoring the project in teamwork encourages students to understand long-term behavioural change as a collective effort that extends beyond the individual.

ii. Carrying out the lesson

Activating prior knowledge

Students should have a basic understanding of fundamental plant concepts, including plant needs, components, classification, and life processes, which would have been introduced at the primary school level. This lesson builds upon their foundational knowledge while reinforcing their understanding through experiential, hands-on activities.

Activity 1

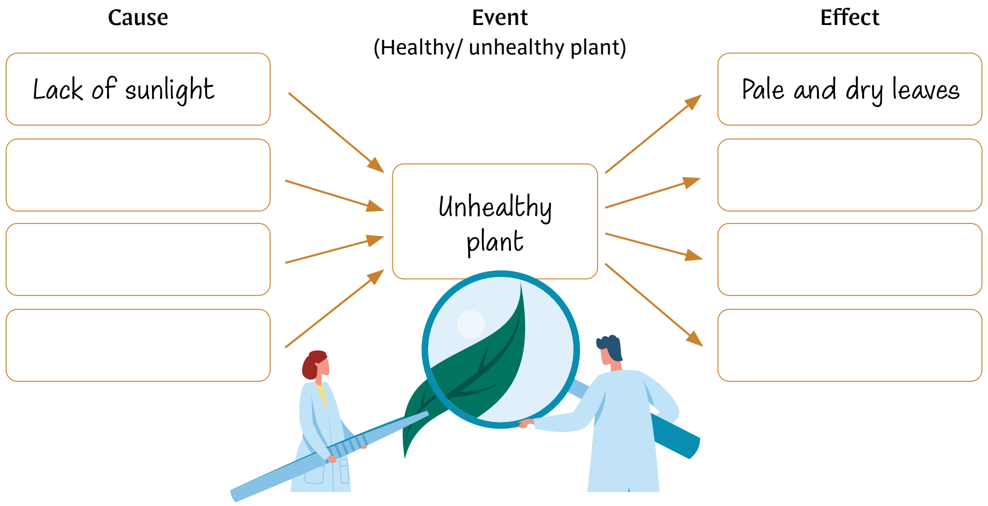
Exploration of cause and effect of plant needs (1 hour)

Materials used:

- *Pictures of healthy and unhealthy plants*
- *Real plant samples*
- *Chart paper and markers*

The teacher began the lesson by engaging students with driving questions, such as: *How can we differentiate between a healthy and an unhealthy plant? Why do some plants become unhealthy?*

Students worked in pairs to observe plant samples and discuss what would happen when a plant lacked its essential resources, suggesting tentative causes as they co-construct a “cause and effect of plant needs concept map”.



Example of a cause and effect of plant needs concept map, to be filled in by students

Activity 2
Investigation on the effect of sunlight
(1 hour)

Materials used:

- *Light intensity meter*
- *Compass*
- *School map*
- *Reference table*
- *Investigation worksheet*

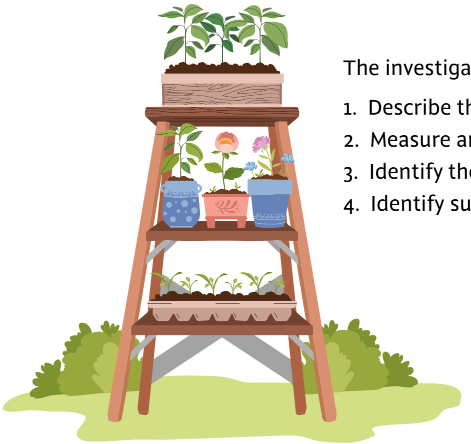
Groups used a light intensity meter to collect readings from two different locations on the school grounds. The readings were recorded on their investigation worksheet. Based on these readings, students justified and selected the best site for the school garden and the plants suitable for that area by referring to the reference table provided by their teacher.

A light intensity meter in use

Reference table

Full sun ***(Cahaya matahari penuh)*** Areas exposed to **direct sunlight for ≥6 hours per day** (e.g., open fields, edges of school compound) ~1000–2000 µmolm^{-2}·s^{-1} PAR	**EXAMPLES OF SUITABLE PLANTS** *(local context)* **Vegetables:** Chilli *(cili)*, okra *(bendi)*, long beans *(kacang panjang)*, tomato, eggplant *(terung)*, spinach *(bayam)* **Flowers:** Sunflower *(bunga matahari)*, marigold *(bunga tahi ayam)* **Herbs:** Lemongrass *(serai)*, basil, rosemary **NOTES FOR SCHOOL GARDENS** Water regularly in the morning. Add mulch or coconut husk to retain soil moisture. Ideal for open spaces or near fencing.
Partial sun/shade ***(Separuh cahaya matahari)*** Areas receiving **3–6 hours of sunlight per day** (e.g., near school walls, under netting) ~400–800 µmolm^{-2}·s^{-1} PAR	**EXAMPLES OF SUITABLE PLANTS** *(local context)* **Leafy Vegetables:** Water spinach *(kangkung)*, mustard greens *(sawi)*, bok choy, lettuce **Herbs:** Mint *(pudina)*, coriander *(ketumbar)*, parsley *(daun sup)* **Flowers:** Begonia, impatiens **NOTES FOR SCHOOL GARDENS** *Best for tropical leafy greens that wilt easily under strong sunlight. Water twice daily during hot weather.*
Filtered light ***(Cahaya tapisan/Di bawah jaring hijau)*** Light passes through **shade nets or greenhouse covers**, reducing intensity but maintaining warmth ~300–600 µmolm^{-2}·s^{-1} PAR	**EXAMPLES OF SUITABLE PLANTS** *(local context)* **Nursery plants:** Seedlings of *sawi*, tomato, and chilli **Spices:** Ginger *(halia)*, turmeric *(kunyit)*, galangal *(lengkuas)* **Tropical ornamentals:** Orchid *(orkid)*, heliconia **NOTES FOR SCHOOL GARDENS** *Suitable for seed germination and early plant growth. Use 50% shade netting to prevent seedling burn.*
Shade/low light ***(Cahaya render/naung an)*** Locations with **<3 hours of sunlight per day** (e.g., under big trees, covered corridors) ~50–300 µmolm^{-2}·s^{-1} PAR	**EXAMPLES OF SUITABLE PLANTS** *(local context)* **Ornamental foliage:** Snake plant *(Lida mak mertua)*, money plant *(pothos/sirap duit)*, peace lily **Indoor plants:** Calathea, ferns, dracaena **NOTES FOR SCHOOL GARDENS** *Use well-draining soil. Avoid overwatering. Perfect for beautifying shaded school corridors or indoor corners.*

Source: Adapted from the Department of Agriculture Malaysia (2021), MARDI (2020), and UPM Faculty of Agriculture (2018), supported by FAO (2019) and Taiz et al. (2018) for light intensity classification and plant growth correlation



The investigation worksheet invited students to:

1. Describe the light conditions
2. Measure and record light intensity
3. Identify the optimal location and direction of plot
4. Identify suitable plant types for this location based on light availability

Tips

1. Depending on the location of your school, you may find that the light conditions listed do not apply to your region. Adapt the table by adding or modifying columns to include locally-relevant factors such as notes and tips suitable for native plant growth according to the climate type (e.g., arid, dry, or coastal environments), seasonal changes, and temperature tolerance.
2. Create intentional spaces for discussion and critical analysis by inviting groups of students to share their data sets and chosen locations. Then, discuss why they are similar or different. Students can learn about and reflect on concepts such as data variability, sources of error, and the importance of repeatability of scientific procedures.

Activity 3

Plant classification gallery walk

(1 hour)

Materials used:

- *Plant samples or pictures*
- *Magnifying glasses*
- *Plant classification worksheet*

Before conducting this activity, the teachers set up five learning stations as follows:

Station 1:
Flowering plants

Station 2:
Non-flowering seed plants

Station 3:
Spore-producing plants

Station 4:
Spore-producing non-vascular plants

Station 5:
Reflection & classification challenge

Station	Activity focus	Specimens/pictures	Intended learning outcomes
1. Flowering plants (angiosperms)	Plants that reproduce through **flowers and seeds inside fruits**	Hibiscus, chili plant, tomato, balsam, okra	Students observe different parts of flowering plants (i.e., stamen, pistils, petals) and describe how flowers produce seeds.
2. Non-flowering seed plants (gymnosperms)	Plants that reproduce by **naked seeds (not enclosed in fruit)**	Pinecone, cypress branch, or other conifers	Students compare gymnosperms with flowering plants and identify that gymnosperms have seeds that are not enclosed by fruit.
3. Spore-producing plants (ferns)	Plants that reproduce by **spores instead of seeds**	Fern leaves, fern sori	Students observe sori (spore cases) and describe that ferns reproduce through spores located under the fronds.
4. Spore-producing non-vascular plants (mosses)	Plants that reproduce by **spores** and lack true roots or vascular tissues	Moss	Students observe and identify mosses as simple plants that reproduce by spores in wet environments.
5. Reflection & classification challenge	Classify plants by their **reproductive method**	Various plants from the four stations	Students classify plants based on their reproductive method.

Students observed the pictures and/or real specimens of plants and plant parts closely, rotating through each station to learn about and classify plants that reproduce by seeds and those that reproduce by spores. By completing the plant classification worksheet with their observations, students created their own plant classification chart after they visited the four stations.

SCAN TO VIEW
The plant classification worksheet

Activity 4
How many chili plants can we grow?
(1 hour)

Materials used:

- *Graph/grid paper*
- *Ruler*
- *Pencil*
- *Calculator*

The teacher began the activity by asking, *"Why is plant spacing important?"* to activate prior knowledge about plant growth and their resource needs.

Students were then presented with the following challenge: *"You have a 20ft x 20ft garden. Each chili plant requires 2ft x 2ft of space. How many chili plants can you grow?"*

Next, the teacher posed guiding questions, such as *"Should we leave space for walking paths or for maintenance purposes?"* to encourage critical thinking and practical planning.

A to-scale version of the garden was shown on graph paper (e.g., 1ft = 1cm) as a guide to aid students in visualising the layout.

Students calculated the area and perimeter of the garden and applied the spacing rule to determine the ideal number of chili plants that can be planted considering factors, such as space for accessibility and garden maintenance.

Activity 5
Designing a STEM garden
(1 hour)

Materials used:

- *Graph/grid paper*
- *Coloured pencils*
- *Sustainability checklist*

Students were grouped in teams of 3–5 garden planners. To encourage students to embrace sustainable practices in their STEM garden designs, a sustainability checklist was given to prompt students to incorporate eco-friendly elements.

Sustainability checklist

Sustainability element	Criteria/questions to consider	Tick (√)
Water management	Is there a method for water conservation (e.g., rainwater harvesting, reuse of water)?	
Plant diversity	Does the design include a mix of plants (vegetables, herbs, flowering plants)?	
Spacing and layout	Are plants spaced appropriately to ensure healthy growth and sunlight access?	
Soil health	Does the design include compost areas or natural fertiliser use?	
Sunlight consideration	Is the garden positioned to optimise sunlight exposure for different plants?	
Waste management	Does the plan include composting or recycling of garden waste?	
Biodiversity support	Does the garden attract pollinators (e.g., bees, butterflies) or provide habitats for small creatures?	
Maintenance feasibility	Can the design be maintained easily by students and teachers?	
Aesthetic and educational value	Does the garden enhance the school's environment and support learning?	

Using the materials provided, the students designed a STEM garden layout that:

1. Adhered to the 20ft x 20ft garden size
2. Included at least three types of suitable plants (e.g., vegetables, herbs, flowers)
3. Considered plant spacing, sunlight direction, and intensity
4. Included features that promote sustainability (e.g. rainwater collection, composting, biodiversity zones)

Activity 6
Group presentation
(1 hour)

Materials used:

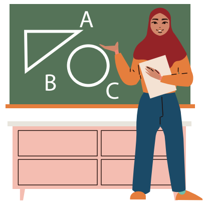
- *Graph/grid paper or presentation programmes/platforms (e.g., Powerpoint, Canva)*
- *Marker pen (if graph paper is used)*
- *Marking rubric*

SCAN TO VIEW
The presentation marking rubric

Roles were assigned for each group. Depending on the number of group members, the roles can include:

A designer who prepares the presentation of the garden layout

A presenter who communicates the group's design ideas



A researcher who provides the scientific reasoning and mathematical justification for the garden's design

Groups presented their garden design and were assessed by their teacher.

Activity 7
Reflection and stewardship journal

Materials used:

- *Journals*
- *Reflection prompts*
- *Videos and articles*

To connect the project back to students' real-world contexts and lived experiences, the teacher shared articles or videos regarding sustainability concerns closer to home. These included:

Johor river pollution

Water pollution effects on the environment

The lesson was brought to a close with individual student reflection in their stewardship journal. Students reflected on environmental care and teamwork, guided by reflection prompts, such as:

- What did I learn about sustainability today?
- How did my group work together effectively?

My stewardship journal

Name: ____________________

Class: ____________________

Reflection area	Guiding prompts	My reflection/response
1. **Understanding sustainability**	What did I learn about sustainability today? How does it relate to the STEM garden project?	
2. **Real-life environmental connection**	Can I relate what I learned (e.g., pollution, water management, biodiversity) to my own life or community?	
3. **Personal actions for stewardship**	What can I personally do to protect the environment in my school or home?	
4. **Teamwork and collaboration**	How did my group work together during the STEM garden activities? What did we do well? What could we improve next time?	
5. **Growth as a STEM steward**	How has this project changed my attitude or habits towards sustainability?	

Teachers assessed the depth of each journal reflection according to this rubric:

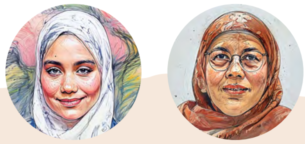
	Criteria	
	Environmental stewardship	Teamwork & collaboration
Excellent (4)	Consistently demonstrates strong awareness of sustainability; provides **specific real-life examples** (e.g., recycling, water-saving, organic planting) and clearly connects them to the garden project.	Actively contributes to the team; takes on **leadership or supportive roles**; encourages equal participation; group work reflects effective collaboration.
Proficient (3)	Demonstrates good awareness of sustainability; provides **some examples** of sustainable practices and makes a basic connection to the garden project.	Participates regularly; **fulfils assigned role responsibly**; works well with peers, though collaboration could be improved.
Developing (2)	Shows limited awareness of sustainability; provides **few or vague examples**, with minimal connection to the garden project.	Participates occasionally; **role performance is inconsistent**; relies on others to complete tasks.
Beginning (1)	Shows little or no awareness of sustainability; **unable to provide examples** or connect ideas to the garden project.	Rarely participates; **avoids responsibility**; hinders group progress.

The teacher then closed the lesson with a sharing circle to build community.

Deforestation in Pahang for oil palm plantations

iii. Challenges and solutions in lesson implementation

Challenge	Potential solution
Located in a rural area of Pahang, Malaysia, the school may face low internet connectivity, which could disrupt the use of applications or computer-based activities.	Graph/grid paper-based activities, and downloadable videos selected in advance can be prepared to ensure they are accessible offline. Teachers can creatively utilise natural resources from around the school, to introduce students to local plants and crops as authentic teaching materials.
As classes are large in number, retaining a group size of 3–5 students results in many groups and presentations to be evaluated. This takes up more class time than initially allocated.	Teachers can assign peer-assessment or peer-feedback using simple rubrics so that groups evaluate each other's work before the teacher's final review. Alternatively, teachers may request groups to submit their work in written or digital form (e.g., as photos or through Google Form responses), allowing the teacher to provide feedback outside of class time.



Authors' reflections

While this project was conducted as a full-day STEM lesson, each activity can be conducted during regular class time, as the content aligns with the existing Malaysian national curriculum standards. To ensure smooth implementation, the lesson plan must be adapted to fit either a single or double 30-minute class slot set by the Ministry of Education.

As the integration of several subjects within a single project requires an extensive range of topics that must be covered prior to the STEM lesson, early preparations (e.g., advance allotment of co-curriculum session times) are needed to align project-based activities with the curriculum while ensuring that students are adequately prepared for their final written examination.

Lastly, the RITE STEM framework offers a structured, iterative pathway for teachers to continuously reflect on and enhance their lesson design. The four phases act as systematic guides for improvement: The Refer phase ensures relevance of curriculum content and students' prior knowledge to community contexts; the Improve phase supports refinement of pedagogical strategies, assessments, and learning outcomes to support student understanding accordingly; the Transfer phase offers insights into activities that foster student engagement and active learning; and the Evaluate phase facilitates lesson implementation review, allowing teachers to collect evidence of students' learning and feedback to make informed decisions on the clarity, flow, and scaffolding needs in the next cycle. Together, these phases comprise a continuous improvement loop that strengthens the quality and impact of the single-day STEM lesson over time.

Assistant Professor Dr Norazsida Ramli & Professor Emeritus Dato' Dr Noraini Idris

Closing Message

Thank you for making it to the end of the publication, *STEM Education in Culture and Context*. We hope you have found it useful, relatable, and actionable. Be sure to check out both parts 1 and 2 of the title for a holistic perspective on STEM Education in Asia.

Readers familiar with our *Making HEADway* handbook series may recognise an earlier edition of this work, *Teaching STEM in Southeast Asia,* developed during the COVID-19 crisis to support efforts in mitigating learning loss. In this revised volume, we have expanded the scope of the series to present a broader range of innovative and practical approaches to STEM education in Asian classrooms.

This publication is also the second in the series to adopt a comprehensive compendium format, following *Becoming Leaders in Sustainability Education*. This reflects our renewed commitment to developing the series as a relevant and robust resource for educators across the region.

SCAN TO ACCESS
The complete suite of handbooks

The diversity of lessons presented across subjects highlights that there is no single way to introduce integrated STEM in the classroom. Rather, educators can consider multiple entry points, adapting approaches to suit their context and student readiness. Often, the greater challenge lies not in the complexity of tools or content, but in finding synergy and alignment with fellow educators and making space for iteration and reflection. Teachers can be creative and collaborative in structuring cross-disciplinary lessons, while using simple yet effective pedagogies that enhance learning experiences. We hope this book affirms the formative impact of STEM education on student development, while offering accessible and innovative ways to bring it into practice.

I would like to thank our contributors and consultant editor for their patience, ingenuity, and dedication in bringing this publication together. It has been an eye-opening experience understanding the many ways STEM education is being shaped and sustained across the region.

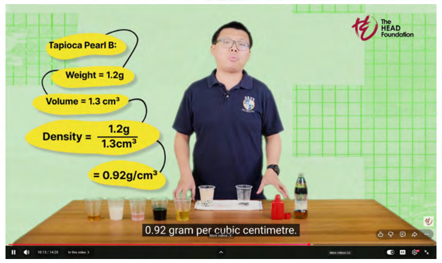
I hope you will find value in applying these insights to your own teaching practice. I also invite you to connect with us on social media and share your reflections with a regional community of educators.

Hillary Loh
Managing Editor,
STEM Education in Culture & Context
Manager, Education Programmes
The HEAD Foundation

About

Making HEADway

Making HEADway was conceived, designed, and launched by The HEAD Foundation in 2020. This expanding suite of teacher professional development offerings includes practitioner-focused handbooks for educators, instructional YouTube videos for live lesson demonstrations, webinars, and more. This open access ecosystem focuses on building up teacher capacity and communities of practice among Southeast Asian educators.



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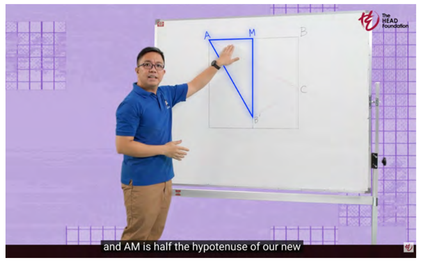
Making HEADway CLASSROOM

The latest edition to the ecosystem, Making HEADway Classroom videos feature live lesson demonstrations from exemplary educators in Asia. Pick up detailed lesson ideas, and watch how educators move through lessons in real time to deliver them in a practical and engaging way.

Scan to watch the full playlist!



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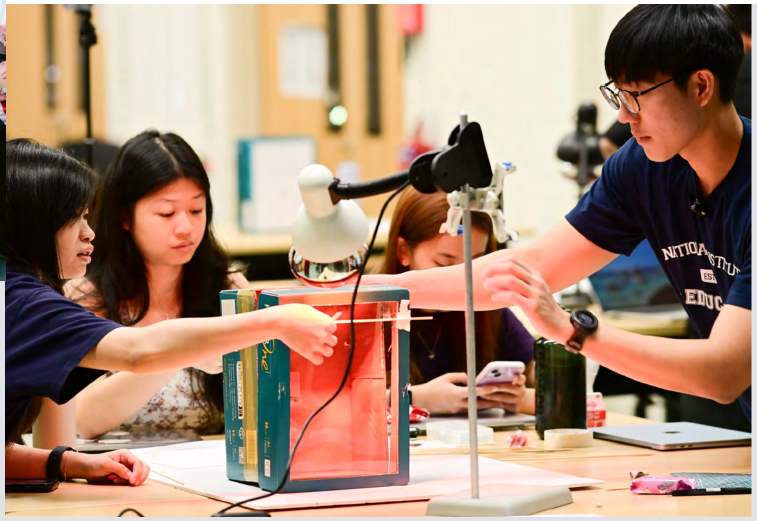
About

meriSTEM@NIE

Positioned at the intersection of theory, pedagogical practice, and empirical research, the Multi-centric Education, Research and Industry STEM Centre at the National Institute of Education (meriSTEM@NIE) in Singapore drives innovation within the evolving local and global educational landscape. Led by a core mission to enhance the quality of cross-disciplinary STEM literacy and competencies, the centre serves as a research-driven hub that connects academic institutions with industry stakeholders.



Through robust collaborative networks comprising STEM specialists, researchers, academic researchers, educators, and industry leaders, meriSTEM@NIE provides the foundational framework for systemic integration and dissemination of STEM education. This is achieved through teacher- and student-capacity building initiatives, targeted undergraduate and graduate-level courses, and access to pedagogical materials such as peer-reviewed research and toolkits for practitioners and learners alike.

The centre advocates for a unified initiative for the pervasive integration of STEM education, while serving as a strategic regional anchor within Singapore's educational ecosystem.

Visit the centre's online platform to explore more on the research, resources, and partnership opportunities

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