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Science and Engineering Practices: a Comparative Analysis of Indonesian, Thai and Vietnamese Science Curricula

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Abstract

Southeast Asian countries are embracing updated integrated curricula, such as STEM, which are impacted by socio-scientific, political, and economic reasons related to global educational reform. This study compares science curricula regarding science and engineering practices (SEPs) in Indonesian, Thai, and Vietnamese science curricula. The SEPs in the curricular learning outcomes were examined using qualitative content analysis. According to the analysis, the learning outcomes of the three Southeast Asian countries were more aligned with science than engineering. Students most often practiced 'constructing scientific explanations,' while the least common was 'asking questions and defining problems' across countries. Compared to Indonesia and Vietnam, the Thai curriculum typically included 'developing a model', a key science and engineering practice. The findings suggest that curriculum design may reconsider integration, curricular coherence, and learning goals for modelling, asking questions, and engineering to increase engagement with diverse activities.

Keywords

science and engineering practices – science education curriculum – STEM education – comparative education

1 Introduction

The integration of science and engineering practices (SEPs) into science curricula has gained prominence in recent years, driven by a growing recognition of their importance in fostering a deeper understanding of scientific inquiry and preparing students for the challenges of the 21st century (Brand, 2020; Simarro & Couso, 2021). SEPs encompass a range of cognitive, social, and physical activities that scientists and engineers employ to investigate phenomena, construct explanations, and design solutions (Brand, 2020; McNeill et al., 2018; NGSS Lead States, 2013). By engaging in these practices, students develop critical thinking skills, problem-solving abilities, and a more authentic understanding of the nature of science and engineering.

SEPs are considered significant to student outcomes because scientists and engineers use them to produce knowledge (Knorr-Cetina & Reichmann, 2015). For example, the US Framework for K–12 Science Education and the Next Generation Science Standards (NGSS Lead States, 2013) contain eight SEPs: asking questions and defining problems; developing and using models; using mathematics and computational thinking; analyzing and interpreting data; engaging in arguments from evidence; planning and carrying out investigations; constructing explanations and designing solutions; and obtaining, evaluating, and communicating information.

1.1 *Global and Regional Emphasis on SEP Integration*

Globally, there has been a push to incorporate SEPs into science education, particularly in the context of STEM (science, technology, engineering, and mathematics) education initiatives. STEM education has been prioritized as a major policy driver to help nations progress economically (Bell et al., 2017; McFadden & Roehrig, 2020), with the hope that it will equip learners with the necessary skills to excel in the 21st-century workforce (Bybee, 2011). Reformers seek to enhance educational outcomes through more precise STEM standards in the curriculum (Reiss & Mujtaba, 2017; Roehrig et al., 2021). Official curriculum documents serve as a reflection of state priorities, defining educational standards, specifying goals, objectives, content, and assessment, and ultimately impacting learning and workforce participation (Wei & Ou, 2019). In Southeast Asia, governments are implementing standards-based reforms in

STEM education to promote cohesion in achieving national goals and further economic development (Cheng, 2022).

1.2 *Purpose and Significance of SEP Comparative Analysis*

However, despite the growing emphasis on STEM education and the recognized importance of SEPs, there is a lack of research examining how SEPs are actually integrated into science curricula across different countries (Brand, 2020; Simarro & Couso, 2021). This gap is particularly pronounced in Southeast Asia, where rapid educational reforms are underway. Understanding the similarities and differences in SEP integration across diverse educational contexts is crucial for informing curriculum development and ensuring that science education effectively prepares students for the demands of the 21st century.

This study seeks to addresses this gap by examining the similarities and differences in the distribution of SEPs within the science curricula of Indonesia, Thailand, and Vietnam. In addition to building on existing international comparative studies on science education – which have largely focused on processes of curriculum change (Vulliamy et al., 1997), curricular aims and ideologies (Mnguni et al., 2020), and implementation challenges (Lin et al., 2020) – this research also explores the potential of influence the interpretation and enactment of SEPs. The study aims to contribute to a deeper understanding of how cultural factors may shape SEP integration, offering new insights into science education curriculum studies within Southeast Asia.

1.3 *Research Questions*

To achieve these objectives, the study addresses the following research questions:

1. How are science and engineering practices (SEPs) distributed and emphasized within the science curricula of Indonesia, Thailand, and Vietnam?
2. What are the general profiles of SEP integration across the science curricula in the selected countries?
3. How does the integration of SEPs vary across countries with distinct cultural and educational traditions, specifically in Southeast Asia?

2 Science and Engineering Practices (SEPs) in STEM Education Context

Recent research on STEM in curricula has primarily focused on two aspects: its characteristics (level of integration, content analysis, design principles, implementation issues) (Lin, et al., 2021; Roehrig et al., 2021) and its various impacts on students (Gale et al., 2020) and teachers (Krell et al., 2015; Ogodo, 2023). Elucidating the intricacy and interplay between science and engineering represents a formidable task. Historically, studies have concentrated on combining science and mathematics, with little consideration given to technology and engineering (Bybee, 2013). However, the inclusion of engineering principles and methodologies in science standards at both state and national levels (NGSS Lead States, 2013) has broadened the scope of integration beyond the realms of science and mathematics, resulting in a renewed emphasis on integration. Involving students in engineering design necessitates an interdisciplinary approach that incorporates knowledge from science, mathematics, and technology (Douglas et al., 2004; Lin et al., 2021).

2.1 *The Role of SEPs in STEM Education and Curriculum Design*

To develop a robust conceptual framework for STEM education, it is essential to have a profound comprehension of the cognitive processes involved in learning, specifically within the realm of teaching and learning STEM disciplines (Roehrig et al., 2021). STEM education prioritizes practical utilization, problem resolution, and direct involvement in STEM subjects (McFadden & Roehrig, 2020). The goal is to enhance students' understanding of these subjects by establishing meaningful connections between classroom concepts and real-world applications. STEM learning is driven by scientific inquiry and engineering designs (McNeill et al., 2018; Papakonstaninou & Skoumios, 2021). Engineering design accelerates STEM education by integrating the STEM disciplines (Lin et al., 2021). This procedure is crucial for making informed decisions in the design stage. Science and engineering encompass groups of individuals who engage in a shared set of activities and knowledge, with Science and Engineering Practices (SEPs) serving as objectives for STEM education (Brand, 2020; Simarro & Couso, 2021; Roehrig et al., 2021).

Practices, once confined within the inquiry cycle, are now recognized as part of a broader framework encompassing aims, societal factors, and norms that constitute the core elements of science and engineering (Erduran & Dagher, 2016; Cherbow et al., 2020). McNeill et al. (2018) proposed a comprehensive categorization of the eight NGSS practices, grouping them into three overarching categories: investigating practices, sensemaking practices, and critiquing practices (Table 1).

2.2 *Adaptation of the SEP Framework for Southeast Asian Contexts*

In our study, we adapted the McNeill et al. (2018) framework in two significant ways. First, we included 'sub-SEPs' to provide a more granular analysis of the practices. Second, we consider contextualized epistemic practices, such as oral

TABLE 1 Tripartite SEP framework (adapted from McNeill et al., 2018)

Categories (McNeil et al., 2018)	**Main SEPs (NGSS Lead States, 2013)**	**Sub-SEPs**
Investigating practices: Engage students in asking questions and implementing data collection methods	SEP1: Asking scientific questions and defining engineering problems	1A: Question and then formulate a scientific question about a phenomenon
		1B Ask a question(s) to define a problem, need, or desire that suggests an engineering problem
	SEP3: Planning and carrying out investigations	3A: Identify the (engineering and control) variables, make decisions about which ones should be recorded, and design ways to measure them
		3B: Conduct a scientific investigation and collect data
		3C: Analyze and identify the effectiveness, efficiency, and durability of designs under a range of conditions
	SEP5: Using mathematics and computational thinking	5A: Represent the relationships among variables by constructing simulations, statistically analyzing data, and applying quantitative relationships
		5B: Analyze design possibilities and acceptable budgets using mathematical analyzes
Sensemaking practices: Students analyze data and design representations based on those data to explain how and why phenomena occur	SEP4: Analyzing and interpreting data	4A: Use a variety of tools to identify the significant features and patterns of data
		4B: Analyze data collected in tests of designs and investigations to compare different solutions and identify the best solutions to meet the criteria and constraints
	SEP6: Constructing scientific explanations and designing engineering solutions	6A: Construct logically coherent explanations of phenomena with available evidence
		6B: Use models representing phenomena when constructing explanations
		6C: Propose systematic processes and solution results for solving engineering problems based on scientific knowledge, balancing competing criteria related to desired functionality, feasibility, cost, safety, aesthetics, and compliance with legal requirements

TABLE 1 Tripartite SEP framework (adapted from McNeill et al., 2018) (*cont.*)

Categories (McNeil et al., 2018)	**Main SEPs (NGSS Lead States, 2013)**	**Sub-SEPs**
		6D: Recognize there is no single best solution but rather a range of solutions
	SEP2: Developing and using models	2A: Construct, develop, and use a variety of models or simulations to predict or explain a phenomenon
		2B Use models and simulations to analyze or test existing systems or proposed systems
		2C: Recognize the strengths and limitations of designs
Critiquing practices: Students evaluating different claims, representations, and texts	SEP7: Engaging in argument from evidence	7A: Provide reasoning and argumentation to identify the best possible solution to a problem as well as the strengths and weaknesses of proposed scientific explanations; Formulate evidence based on data and develop arguments based on evidence to defend conclusions
		7B: Collaborate with peers to search for the best explanation for investigating a phenomenon; Collaborate throughout the design process
	SEP8: Obtaining, evaluating, and communicating information	8A: Evaluate the scientific validity of the information thus acquired and integrate this information
		8B: Derive meaning from scientific media and communicate findings clearly and persuasively to express ideas and investigative results both orally and in written form using a variety of graphic organizers
		8C: Engage in discussion with peers

and graphical communication, that are relevant to epistemic communities in Indonesia, Thailand, and Vietnam. This adaptation allows us to analyze practices within the curriculum while considering the broader context suggested by Dagher and Erduran (2016), thus providing a more comprehensive understanding of how these practices are embedded in science education within Southeast Asian contexts.

Science education curricula in Southeast Asian countries have undergone significant changes over the last 70 years since the end of World War II. The latest renewal of their science education curricula has focused on the integration of practices and content related to STEM (Islami et al., 2022). This study analyzes the integration of these practices into science curricula, considering the unique cultural and educational contexts of Indonesia, Thailand, and Vietnam. By utilizing this adapted framework, we aim to investigate SEPs in the curricula of these countries, considering both the universal aspects of science and engineering practices and the specific ways they are interpreted and implemented in Southeast Asian educational systems. This approach allows us to explore how global trends in STEM education are localized and adapted to meet the needs and priorities of different national contexts.

3 Research Methodology

3.1 *Research Design and Framework Adaptation*

This study adopted a descriptive qualitative research design (Creswell, 2020) to analyze the integration of Science and Engineering Practices (SEPs) in the science curricula of Indonesia, Thailand, and Vietnam. This approach allowed us to gather rich textual information and offer nuanced interpretations of practices embedded in the science education curricula of these Southeast Asian countries. While we used a framework of sense-making, investigating, and critical practices derived from the US Next Generation Science Standards (NGSS Lead States, 2013), we were cautious not to position the NGSS as a form of epistemic governance over local science curricula. Instead, we viewed the eight SEPs addressed in the NGSS as frames of reference to understand how scientists and engineers might work. To address potential cultural biases, we held extensive team meetings to discuss this issue and decided to include local practices in our SEP framework, recognizing them as constitutive of scientific and engineering work in these contexts (Table 1).

Following Powell's (2020) guidance on international comparative research, we assembled a large international research team to enhance our ability to work across cultures and make explicit comparisons. This collaborative approach enabled us to learn from each other and gain deeper insights into the science curricula across borders. We attempted to situate points of interest within national contexts and global policy frameworks to better understand the practical orientation of each nation's science curriculum.

3.2 *Curriculum Selection and Comparative Focus*

We selected three middle school science curriculum documents for analysis: Indonesia, Thailand, and Vietnam. Indonesia's curriculum is based on a "basic competence" model applied to STEM curricula (Ministry of Education and Culture, 2017), integrating STEM concepts and practices into the core competencies expected of students. Thailand's curriculum emphasizes the need for cross-disciplinary integration in applying knowledge to problem-solving (Institute for the Promotion of Teaching Science and Technology [IPST], 2015), aiming to develop students' ability to apply STEM concepts across different disciplines. Vietnam's curriculum has recently adjusted the learning outcomes of its science courses to align with STEM education principles (ABD, 2016; Bien et al., 2019; To Khuyen et al., 2020), reflecting efforts to modernize its science education in line with global STEM trends. These documents were chosen because they represent major curricular changes in science education within each country, with emphases on renewing STEM purposes, pedagogies, and practices.

To ensure comparability, we focused on science curricula at the middle school level across each country. In most countries, this level encompasses Grades 7 to 9 (ages 12–14). However, in Vietnam, middle school includes Grades 6 to 9 (ages 11–14). For the purposes of this study, we will analyze Grades 7 to 9 across all countries, maintaining a consistent grade range despite the broader middle school span in Vietnam. We chose to focus on this level because it represents the common science curriculum for all students at the later stage of compulsory education. A key aspect of our analysis was the examination of learning outcomes in each curriculum. Learning outcomes define what students should know, understand, be able to do, and value following a period of learning (Kennedy, 2006). We recognized that these outcomes reflect each country's unique educational priorities and cultural context, and that the characteristics of these learning outcomes vary according to the curriculum and context in each country, which formed a central part of our investigation.

3.3 *Data Collection*

3.3.1 Focus on Middle School Science Curricula for SEP Analysis

For consistency in analyzing SEPs across the three countries, we selected the middle school science curriculum as the primary data source. Middle school, typically spanning three years (ages 12–14), represents a stage when science education is compulsory and standardized for all students. This focus allows for a comparative analysis of SEPs within a common educational level across the different countries.

Science is taught as a core and separate subject in all three countries at this level with different strands and foci. For example, the science curriculum in Thailand comprises four strands: biological science, physical science, earth and space science, and technology (Dahsah & Faikhamta, 2008; IPST, 2015). There are four main subject strands in Vietnam's curriculum: substance and metabolism, living beings, energy and transformation, and the earth and sky (Vietnam Ministry of Education and Training [VMET], 2018). Regarding

Indonesia's science curriculum, five main subject strands were included: living things and life systems; energy and its changes; material and its changes; earth and space sciences; and science, environment, technology, and society (Indonesian Ministry of Education and Culture, 2017).

3.3.2 Identification of Common Domains and Data Collection Process

Through an examination of these subject strands, five common domains were identified for a baseline SEP comparison: chemistry, physics, biology, earth science, and space science. This approach allowed us to create a standardized framework for analyzing SEPs across the three countries, despite differences in curriculum structure and terminology.

We collected and analyzed the official curriculum documents from each country: *Model Syllabus for Junior High School / Madrasah Tsanawiyah (SMP/MTS) Subjects* (Ministry of Education and Culture, 2017), the *Basic Education Core Curriculum B.E. 2551* from Thailand (IPST, 2015), and the *General Education Curriculum* from Vietnam (VMET, 2018). These documents were selected as they represent the most recent major revisions in science education curricula within each country, with an emphasis on updating STEM purposes, pedagogies, and practices.

These documents were selected because they represent the most recent major curricular changes in science education within each country, with emphases on renewing STEM purposes, pedagogies, and practices.

By implementing the data collection systematically, we aimed to enhance the trustworthiness of our study by ensuring that our analysis was based on comparable and comprehensive data from each country. This method allowed us to conduct a rigorous comparative analysis of SEPs while acknowledging and accounting for the unique educational contexts of Indonesia, Thailand, and Vietnam.

3.4 *Data Analysis*

3.4.1 Qualitative Content Analysis and Coding Procedures

Our analysis involved a systematic examination of the selected curriculum documents, employing qualitative content analysis to identify similarities and differences in learning outcomes (Stemler, 2000). We utilized three main coding procedures as outlined by Krippendorff (2004): open, axial, and focused coding. Recognizing the challenges of cross-analysis given the different languages involved, we implemented a rigorous process to ensure consistency and reliability in our coding across all three countries.

The coding process began with initial independent coding, where each country lead coded their own national curriculum using the framework outlined in Table 1. This step ensured that each lead developed an understanding of how the framework applied to their specific context. Following this, the international team held a series of meetings to discuss and compare their coding results. These meetings were crucial for cross-examination of the coding and identification of any inconsistencies.

During these collaborative sessions, we addressed inconsistencies that arose from various sources, including differing interpretations of specific learning outcomes in the context of the framework, nuances in translating the framework across different languages, and varying cultural perspectives on what constitutes a particular SEP. Through extensive discussion and debate, we worked towards consensus on each point of disagreement. This process of collaborative discussion and consensus-building was essential in overcoming the challenges of cross-analysis and maintaining trustworthiness in our findings.

3.4.2 Collaborative Cross-country Analysis and Quantitative Comparison

To illustrate our coding process, consider this learning outcome from Thailand's curriculum: "By investigating renewable energy sources and taking part in practical activities to harness them, I can discuss their benefits and potential." We initially coded this as SEP3 (planning and carrying out investigations) and SEP8 (obtaining, evaluating and communicating information). In the axial coding stage, we further elaborated on these codes. The phrase "By investigating renewable energy sources …" was coded as sub-SEP3B, "conduct a scientific investigation and collect data." The phrase "I can discuss their benefits and potential" was coded as sub-SEP8A, "evaluating the scientific validity of information."

We calculated the percentage of each sub-SEP per learning outcome, referred to as 'PSL'. These percentages facilitated a quantitative comparison of learning outcomes across countries, accounting for the varying numbers of learning outcomes in each curriculum. For example, we found that Thailand's curriculum contained the highest number of total sub-SEPs (294), whereas Indonesia's had the lowest (52). This quantitative approach complemented our qualitative analysis, providing a comprehensive view of SEP integration across the curricula.

By employing this methodological approach, with its emphasis on collaborative coding and consensus-building, we aimed to provide a comprehensive and culturally sensitive analysis of how SEPs are integrated into the science curricula of Indonesia, Thailand, and Vietnam. This approach contributes to a broader understanding of STEM education practices in Southeast Asia while addressing the challenges of cross-linguistic and cross-cultural analysis. The findings from this analysis were instrumental in generating hypotheses and facilitating discussions among country leads and their teams about the SEP profiles in each curriculum, ensuring that our comparative analysis was both rigorous and nuanced.

3.5 *Practices Representations: SEP Profiles*

To analyze the distribution of Science and Engineering Practices (SEPs) across the curricula of Indonesia, Thailand, and Vietnam, we developed the concept of an 'SEP profile.' Each profile is based on the 21 sub-SEPs (labeled 1A to 8C) presented in Table 1. These profiles were constructed by analyzing the learning outcomes of each country's science curricula for grades seven to nine, reflecting the proportion of each SEP within these learning outcomes. Figure 1 provides a sample SEP profile to illustrate this concept.

In Figure 1, the bars are color-coded to represent the three categories of SEPs as adapted from McNeil et al. (2018): blue for investigating practices, orange for sensemaking practices, and green for critiquing practices. The height of each bar indicates the percentage of individual SEPs identified within the learning outcomes, corresponding to the specific sub-SEPs listed in Table 1. The shaded portions of the bars represent the combined percentages of main SEPs within each category. For example, the orange shaded area shows the total percentage of all sensemaking practices. The width of each bar or shaded area indicates the emphasis placed on that particular SEP or category of SEPs in the curriculum.

As an example, interpretation of the sample profile shown in Figure 1, the sensemaking practices (orange) account for a cumulative 38.55% of all SEPs identified. This percentage is composed of data analysis practice (SEP4) at 6.70%, constructing explanation practice (SEP6) at 22.91%, and modelling practices (SEP2) at 8.94%. Within the sensemaking category, we made careful distinctions between similar practices. For instance, both '2B Use models and simulations to analyze or test existing systems or proposed systems' and '6B Use models representing phenomena when constructing explanations' involve modeling. We differentiated these based on their primary purpose.

To illustrate this distinction, consider two examples from the Vietnamese curriculum. The learning outcome "Draw a circuit diagram with symbols describing resistance, bell, ammeter, voltmeter, optical resistance, diodes, and light-emitting diodes" (Vn-82015) was coded as 2B because it involves working with an existing circuit model. In contrast, "Indicate whether the refractive index is equal to the ratio of the speed of light in the air (or vacuum) to the

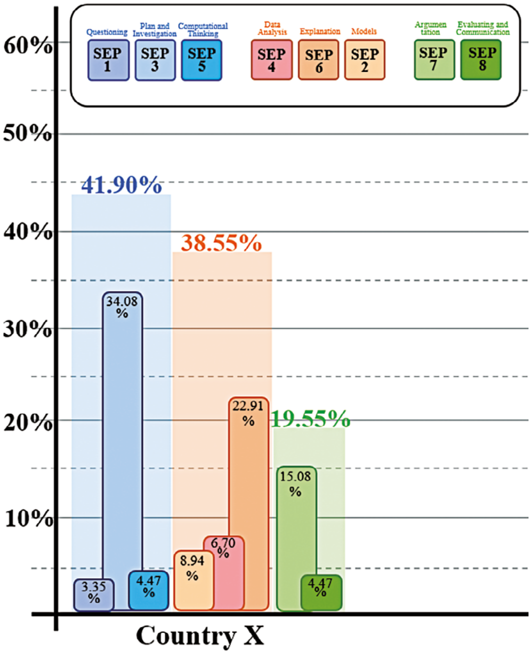

FIGURE 1 Sample SEPs profile

speed of light in the medium" (Vn-92004) was coded as 6B because it uses a model of light to construct an explanation about refraction.

After constructing individual profiles for each country, we compared these SEP profiles to identify similarities and differences in how SEPs are integrated into the science curricula of Indonesia, Thailand, and Vietnam. This approach allowed us to visualize and quantify the emphasis placed on different scientific practices across the three curricula, providing a foundation for our comparative analysis.

4 Results

In this comparative curriculum analysis, we present both quantitative and qualitative data on Science and Engineering Practices (SEPs) in the grades 7–9 science curricula of Indonesia, Thailand, and Vietnam. Our findings are structured to provide a comprehensive view of SEP integration across these countries. We begin with a broad overview of the general SEP profiles, followed by specific illustrations from individual subject strands. We then delve into a more detailed examination of SEPs in specific subject areas and analyze the characteristics of learning outcomes and indicators. This multi-layered analysis allows us to generate hypotheses about factors influencing SEP incorporation and to explore similarities and differences across the curricula. We first present an overview of SEP profiles across the three countries, then highlight domains of learning specific to SEP categories. This approach provides a nuanced understanding of how SEPs are integrated into science education in these Southeast Asian contexts.

4.1 *General Profiles of SEP Integration in the Selected Science Curricula*

In terms of the learning outcomes of the science curricula (for grades 7 to 9), we found that Thailand and Vietnam contained almost the same number of learning outcomes (176 and 162, respectively), whereas Indonesia's curriculum prescribed significantly smaller amounts of learning outcomes (66). The highest number of total sub-SEPs was in Thailand's science curriculum (294 sub-SEPs), whereas the lowest was in Indonesia (52 sub-SEPs). The number of sub-SEPs in Vietnam's curriculum was 228. Thus, Thailand's curriculum contained the highest number of practices and exhibited much greater curricular differentiation.

Figure 2 presents the proportion of SEPs in each country's science curriculum. In these figures, blue represents investigating practices, orange represents sensemaking practices, and green represents critiquing practices. As shown in Figure 2, the proportionality of practices (investigative, sensemaking, and critiquing practices) within each country suggests an emphasis on ways of conducting STEM. With the notable exception of Indonesia, critiquing had the lowest proportion of coded SEPs. In contrast, investigation was the second most frequent practice promoted in science curricula across all three countries. Sense-making practices were proportionally well represented in Thailand and Vietnam's science curricula, whereas in Indonesia, it was the least represented practice in proportion to the others. Vietnam had the largest range of practice proportions, from 48% to 7% of the science curricula studied. These ratios suggest different emphases on specific scientific practices across curricula. As shown in Figure 2, investigative practices were emphasized more in the Vietnamese curriculum, sense-making practices were more prominent in the Thai curriculum, and critiquing practices were prioritized in the Indonesian curriculum.

When scanning across practices, Figure 2 reveals that Vietnam's science curriculum promotes sensemaking almost as much as investigation (48.25% and 44.30%, respectively), but only one-sixth of its SEPs are devoted to critiquing (7.46%). Thailand's science curriculum focuses largely on sensemaking practices (56.12%) to explain phenomena. Thailand had the highest proportion of

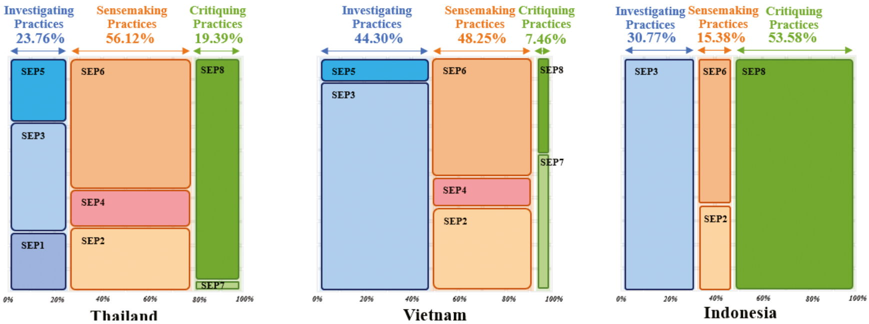

FIGURE 2 The SEPs profiles of select SE Asia science curricula (grades 7–9)

SEPs in this category (56.12%), followed by Vietnam (48.25%) and Indonesia (15.38%). In contrast, as shown in Figure 2, in Indonesia's science curriculum, the highest proportion of SEPs related to critiquing practices (53.58%), with the majority of these SEP focused on argumentation, evaluation, and communication (53.58%). This profile is different from Vietnam's science curriculum country profile, whose critiquing practices are shown in green, are the lowest in proportion to other practices (7.46%), and are in fact the lowest out of all SEPs in any of the profiles. Furthermore, comparing the practice profiles reveals a similar pattern between Thailand and Vietnam's science curricula, where there is an emphasis on both investigating and sensemaking practices, but less on critiquing practices.

Notably, we did not find evidence of several practices in the curricula of grades 7–9. For example, Vietnam's SEP profile did not appear to show any evidence of SEP1 (asking questions and defining problems). Similarly, Indonesia's SEP profile did not appear to show evidence of SEP1, SEP5 (asking questions and defining problems and using mathematics and computational thinking), SEP4 (analyzing and interpreting data), or SEP7 (engaging in arguments from evidence).

4.2 *Investigative Practices in Physics: Beyond Calculations and Formulas*

While investigative practices were present in all examined science curricula, we conducted a more detailed analysis by examining the sub-SEPs associated with these practices. Our findings revealed varying emphases on investigative practices across the three countries. Vietnam's science curriculum showed the highest proportion of general investigative practices (44.30% of 228 total learning outcomes), followed by Indonesia (30.77% of 52 total learning outcomes), and Thailand (24.94% of 294 total learning outcomes).

Within the category of investigative practices, we sought evidence of specific sub-SEPs. Notably, questioning practice and defining engineering problems (SEP1) were not apparent in the science curricula of Vietnam and Indonesia. Additionally, computational thinking (SEP5) was not evident in Indonesia's curriculum. Given these variations, we focused our analysis on planning and conducting investigations (SEP3), which emerged as a common feature across all three countries' science curricula.

To provide a more nuanced understanding of SEP3, we present a detailed example from the physics curriculum. This example illustrates how planning and conducting investigations is integrated into specific learning outcomes, offering insight into the practical application of this investigative practice in science education across the three countries. Figure 3 illustrates the overall investigation practices (SEP3) for all science topics, shown in the lightest blue color. The physics strand can be visualized by grade level (grade 7, grade 8, and grade 9). Figure 3 shows the proportion of SEP3 in the overall science curriculum and in physics topics. The figure also shows the proportion of SEP3 in physics by grade.

Table 2. Textual comparison of 'planning and carrying out investigations' (SEP3) for the topic of circuits in physics in grade 7–9 science curricula across countries.

Our analysis reveals distinct approaches to physics education, particularly in the study of electrical circuits, across Indonesia, Thailand, and Vietnam. Indonesia's curriculum offers the most flexibility, with learning outcomes that do not prescribe specific methods or experiments for circuit design and measurement, implying teacher autonomy in selecting appropriate methods

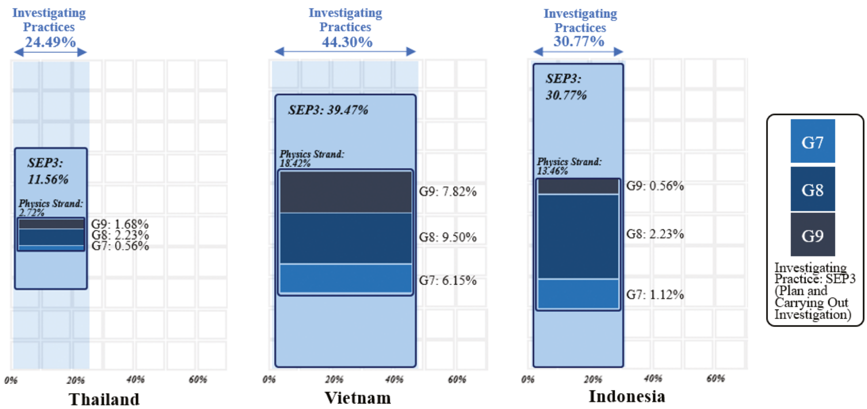

FIGURE 3 The investigating practices profile in the physics across levels (grades 7–9)

TABLE 2 SEP3 profile of 'circuits' across grades 7–9 in science curricula

Thailand	Vietnam	Indonesia
***Th**-92301* Analyze the amounts of voltage and current in a circuit with several resistances in parallel or series, connecting and engaging with explicit evidence ***Th**-92303* Use a voltmeter and ammeter to measure the electrical amounts ***Th**-92307* Draw an electric circuit in parallel and series of resistance	***Vn**-92013* Conduct simple experiments to illustrate in a connected circuit that the current is the same at every point. In parallel wiring, the total current in the branches is equal to the current flowing in the main circuit ***Vn**-92014* Calculate the current in a one-way circuit in parallel in some simple cases	***Id**-92015* Present the results from designing and measuring various electrical circuits

Note: Each country's learning outcomes were systematically labelled as 'Xx-GSs-Oo,' where Xx represents the name of the country, G represents the level/grade, Ss represents the strand and sub-strand, and Oo represents the order of learning outcomes.

and tools. In contrast, Thailand and Vietnam demonstrate a more prescriptive approach. Both countries emphasize specific investigation and experimentation techniques, with Vietnam's curriculum including directives to 'conduct simple experiments' and explore 'parallel wiring,' while Thailand's curriculum mentions 'several resistances in parallel.' Thailand's approach is particularly detailed, expecting teachers to promote the use of specific measurement tools (voltmeters and ammeters), guide students in planning and designing circuits through drawings, and encourage the use of explicit evidence in circuit analysis.

This emphasis on evidence-based learning in Thailand fosters a connection between experimental results and scientific explanations. Vietnam's curriculum similarly prescribes specific types of investigations, dividing learning outcomes for circuits into conducting experiments and performing calculations.

While physics constitutes a relatively small portion of the overall science curricula for grades 7–9 in all three countries, Thailand's curriculum stands out as the most prescriptive, evident in the detailed text and specific directions provided for activities. Indonesia's curriculum, while less prescriptive, still includes outcomes related to presenting, designing, and measuring practices, whereas Vietnam focuses on conducting experiments and performing calculations. Notably, all three curricula go beyond merely stating how to perform science calculations in physics, suggesting the integration of technological tools, design practices, and computation, which aligns with broader STEM principles and Science and Engineering Practices (SEPs). This comparative analysis highlights the diverse approaches to physics education in Southeast Asia, ranging from flexible and teacher-driven methods in Indonesia to more structured and prescriptive approaches in Thailand and Vietnam.

4.3 *Sensemaking Practices in Biology: Developing and Using Models*

Figure 2 depicts the sensemaking practices in the three countries' science curricula. Sensemaking practices comprise SEP2 (developing and using models), SEP4 (analyzing and interpreting data), and SEP6 (constructing scientific explanations and designing engineering solutions). Table 1 outlines the additional sensemaking practices examined, with notable differences in how countries approached engineering problems. For instance, Thailand and Indonesia addressed design solutions for engineering problems (SEP 6C), while Vietnam uniquely emphasized that there is no single best solution (SEP 6D). Biology emerged as a key area for deeper analysis due to its distinctive representation of sensemaking practices. In grades 7–9, Thailand's curriculum contained 40 sensemaking practices out of 67 biology learning outcomes, Vietnam had 51 out of 75, and Indonesia had 2 out of 25.

Constructing explanations (SEP6) dominated the sensemaking practices in biology across all three countries, comprising approximately 32% in Thailand, 25% in Vietnam, and 10% in Indonesia. Figure 4 illustrates the sensemaking practice profile for biology, visualizing the relationships between SEP2 (developing and using models), SEP4 (analyzing and interpreting data), and SEP6 (constructing explanations and designing solutions). The figure presents the proportion of biology-specific sensemaking practices within the overall sensemaking practices for grades 7–9 in each country. Notably, biology accounted for about 13% of all sensemaking practices in Thailand, 21% in Vietnam, and 4% in Indonesia, highlighting significant variations in the emphasis placed on sensemaking within biology education across these Southeast Asian countries.

The practice of developing and using models to understand phenomena serves as a unifying approach in science and engineering education.

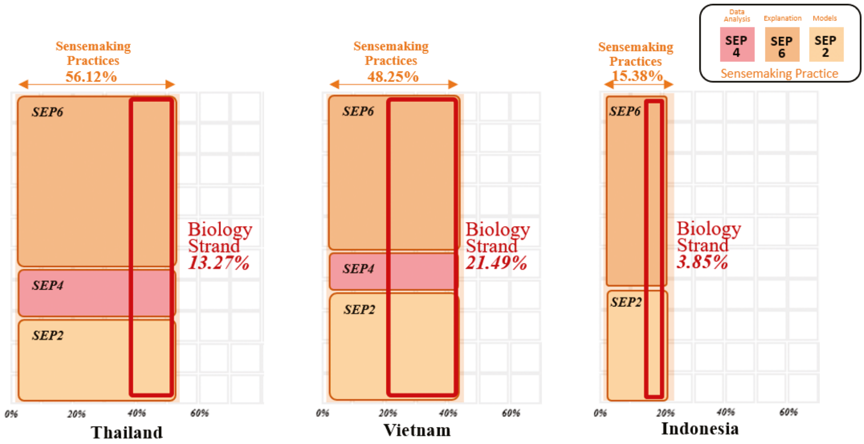

FIGURE 4 A sensemaking practice profile in the biology strand across sensemaking practices

This modeling practice (SEP2) encompasses a range of activities, including constructing models, using simulations to test models, and recognizing the strengths and limitations of model design. Our analysis revealed that all three countries' science curricula for grades 7–9 incorporated this practice, albeit to varying degrees. Notably, we observed overlaps between using models for explanations (sub-SEP 6B) and using models to analyze existing systems (sub-SEP 2B), highlighting the interconnected nature of these practices. Quantitatively, the prevalence of sensemaking practices, which include modeling, varied significantly across the countries: Vietnam's curriculum contained 51 instances, Thailand's 40, and Indonesia's only 2. This disparity underscores the differing emphases placed on modeling and other sensemaking practices in science education across these Southeast Asian countries, potentially reflecting broader educational philosophies or priorities in each nation.

The illustrations of the SEPs for physics and biology strands reveal some differences and similarities among the science curricula in each country, including prescriptiveness and curricular emphasis.

4.4 *Levels of Sensemaking in Biology: Variations in Depth of Understanding*

Our analysis of sensemaking practices in biology curricula across Thailand, Vietnam, and Indonesia revealed significant variations in both quantity and approach. We focused on three types of sensemaking practices: developing and using models (SEP2), analyzing and interpreting data (SEP4), and constructing scientific explanations and designing engineering solutions (SEP6). Vietnam's

TABLE 3 Examples of biological outcomes related to sense-making and constructing scientific explanations (SEP6) across grades 7–9

Thailand	Vietnam	Indonesia
Th-91103 Construct a model to explain energy transference in the food web *Th-71201* Compare shapes, characteristics, and structures of plant and animal cells, then describe the functions of cell walls, cytoplasm, nucleus, vacuoles, mitochondria, and chloroplasts *Th-91307* Describe the use of transgenic organisms and their potential effects on humans and the environment using the collected information	*Vn-81015* Can do projects or exercises: Investigating kidney diseases like kidney stones, kidney inflammation, etc. in school or the local environment *Vn-81025* Investigate the current status of environmental pollution in the locality *Vn-91007* Through an analysis of examples of adaptive evolution, prove the role of natural selection in the formation of adaptive and diverse characteristics of organisms	*Id-81410* Design the excretory system in humans, and discuss its application in maintaining personal health

curriculum contained the highest number of sensemaking practices (40 out of 52 learning outcomes), followed closely by Thailand (36 out of 52), with Indonesia showing significantly fewer (2 out of 15). Constructing explanations (SEP6) emerged as the dominant practice across all three countries, accounting for 31.63% in Thailand, 24.56% in Vietnam, and 9.62% in Indonesia.

Figure 4 illustrates the sensemaking practice profile for the biology strand from grades 7 to 9, visualizing the relationship among SEP2, SEP4, and SEP6. This figure shows the proportion of biology-specific sensemaking practices within overall sensemaking practices: 21.49% in Vietnam, 13.27% in Thailand, and 3.85% in Indonesia. We also identified "non-defined" sensemaking

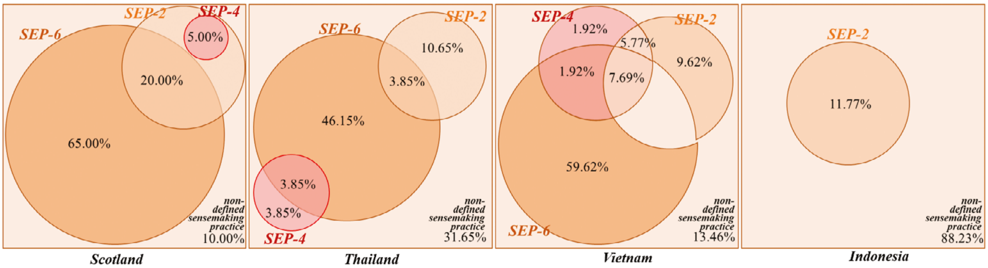

FIGURE 5 An overlap among modeling and other sensemaking practices in the biology strand

practices, particularly prevalent in Indonesia (88.23% of sensemaking practices), compared to 31.65% in Thailand and 13.46% in Vietnam. Examples of these non-defined practices include "compare the biological diversity from the living level to the ecology system level" (Th-91309) and "implementation of a project on food hygiene and safety in the locality" (Vn-81007).

Figure 5 further illustrates the overlaps and relationships among different sensemaking practices. For instance, Thailand's curriculum promoted constructing explanations with and without models, as well as using data, while Vietnam's curriculum showed relationships among all three practices. Notably, Vietnam uniquely combined models and data for explanation construction in 7.96% of its sensemaking practices, exemplified by learning outcomes such as investigating kidney diseases using organ models and local data (Vn-81015 and Vn-81025). This comparative analysis highlights the diverse approaches to sensemaking in biology education across these Southeast Asian countries, reflecting differing emphases on scientific inquiry, explanation building, and the integration of various scientific practices in their respective curricula.

4.5 *Critiquing as a Practice for Enhancing Authenticity in Science Classrooms*

Our analysis of critiquing practices in science curricula revealed significant variations across Indonesia, Thailand, and Vietnam. These practices, which involve engaging in argument from evidence and obtaining, evaluating, and communicating information, encompass skills such as evaluating claims, providing reasoning, identifying strengths and weaknesses of explanations, and formulating evidence-based arguments. Figure 6 illustrates the critiquing practice profile for each country, representing the proportion of learning outcomes in grades 7–9 science curricula that foster these practices. Notably, Indonesia's curriculum showed the highest emphasis on critiquing, with 53.58% of learning outcomes devoted to these practices, followed by Thailand at 19.39%, and Vietnam at 7.46%. Examples from the curricula illustrate how these practices

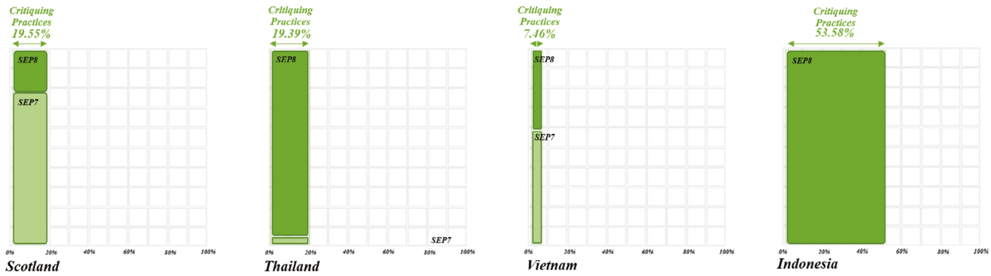

FIGURE 6 A critiquing practice profile across science curricular

are integrated into various scientific topics. In Vietnam, an outcome states, "Having taken part in practical activities to compare the properties of acids and bases" (Vn-72052), encouraging comparative analysis based on experimental evidence.

Thailand's curriculum includes, "Compare the boiling point and the melting point of pure substance and mixtures by measuring the temperature, sketch graph, interpret the data or information" (Th-72104), emphasizing data interpretation and communication. Indonesia's example, "Present the results of investigations or work about the nature of the solution, physical change and chemical change or mixture separation" (Id-71047), requires students to obtain and communicate information. These examples demonstrate how critiquing practices promote skills in data analysis, interpretation, and scientific communication across different contexts, reflecting varying emphases on developing critical thinking and argumentation skills in science education among these Southeast Asian countries.

5 Conclusions, Discussions and Implications

5.1 *Key Findings on SEP Integration in Southeast Asian Curricula*

This comparative study of science and engineering practices (SEPs) in the middle school science curricula of Indonesia, Thailand, and Vietnam reveals how educational foci shape STEM education in Southeast Asia. The distinct patterns observed reflect not only different emphases on SEPs but also deeper values and beliefs about the nature of science and engineering. We analyzed the science curricula in three Southeast Asian countries that have recently undergone major curriculum renewal. We approached our curriculum analysis with a practice orientation, using a tripartite framework of practices adapted from McNeill et al. (2018), which was broad enough to encapsulate practices commonly associated with science and engineering. Comparing SEP1 (asking scientific questions and defining engineering problems), SEP3 (planning and carrying out investigations), and SEP5 (using mathematics and computational thinking) across the three countries, the practice of 'planning and carrying out investigations' was emphasized.

5.2 *Emphasis on Sensemaking, Investigating, and Critiquing Practices*

The practice of sensemaking was evident in all junior science curricula that we examined. Sensemaking practices were most addressed in the Vietnamese and Thai science curricula, while they were least addressed in the Indonesian curriculum. Sensemaking practices include SEP4 (analyzing and interpreting data), SEP6 (constructing scientific explanations and designing engineering solutions), and SEP2 (developing and using models). Modelling can involve analyzing data and constructing scientific explanations, yet it was not the most prevalent sense-making practice encountered. Only the Vietnamese curriculum utilized all three sense-making practices in concert with one another. Our recommendation for science curriculum writers is to consider how practices such as modelling can serve as an anchor for other related practices and act as a bridge between science and engineering disciplines.

The use of models, mathematics, and computation is characteristic of contemporary science and engineering in many ways. Nevertheless, this study found that neither of the former practices were addressed in the Indonesian science curriculum and were addressed less in the other science curricula we compared. Computational thinking may be invoked or subsumed in other practices but is not explicitly prescribed in the curriculum. Li et al. (2020) emphasized developing solutions to specific engineering problems through activities that engage students in computational steps and algorithms. Another way to promote student engagement in these practices is for pre-service teachers to design STEM lessons that include scaffolded activities to foster mathematics and computational thinking to solve problems. In addition to computation, analysis, and interpretation of data before developing and modifying a model and asking for explanations could support the use of modelling practices (Dean & Gilbert, 2021).

Finally, 'critiquing practices' are a process of reaching evidence-based conclusions and solutions. Interestingly, the analysis revealed that critiquing, and in particular, the practice of engaging in argument from evidence (SEP7), was grossly underrepresented in all but the Indonesian curriculum. This finding suggests that argumentation is neither present nor explicitly articulated in the science curricula we compared, except in Indonesia. To foster critique and design STEM activities that include justification and evidence-based argumentation, we recommend providing opportunities to make decisions, communicate findings, and make scientific judgements.

5.3 *Unique Curricular Emphases in Indonesia, Thailand, and Vietnam*

Across all three countries, "planning and carrying out investigations" emerged as a prominent practice, highlighting the importance of inquiry-based learning in science education. However, the study also revealed significant differences in SEP distribution, which can be attributed to each country's unique cultural and contextual influences on curriculum development.

Indonesia's Curriculum 2013 prominently features "obtaining, evaluating, and communicating information" (SEP8), aligning with the country's emphasis on observation and communication (Ministry of Education and Culture, 2017). This focus is likely a strategic response to Indonesia's challenges as the world's largest archipelagic state with over 300 ethnic groups. The emphasis on SEP8 may serve to foster national unity through shared scientific understanding, develop skills crucial for the global knowledge economy, and integrate traditional knowledge with modern scientific practices. The integrated science curriculum, incorporating earth and space science alongside traditional disciplines, reflects Indonesia's rich biodiversity and acknowledges the interconnectedness of scientific disciplines in addressing complex environmental and developmental challenges.

Thailand's curriculum emphasizes 'sense-making' practices, particularly 'developing and using models' (SEP2). This focus on hands-on, inquiry-based learning aligns with Thailand's broader educational reforms and economic goals. The emphasis on cross-disciplinary integration (IPST, 2015) reflects efforts to cultivate strong technological skills among Thai learners. As a result, well-prepared learners are anticipated to become key contributors to Thailand's economic development, positioning the country as a subregional hub for innovation and technology in Southeast Asia (Chirathivat & Cheewatrakoolpong, 2016).

Vietnam demonstrates a balanced approach between "sensemaking" and "investigating" practices, reflecting the country's dual focus on theoretical understanding and practical application. This balance can be attributed to Vietnam's historical emphasis on academic excellence, influenced by Confucian traditions (Tho, 2016), and the need for both knowledge and skills in a rapidly developing economy. Recent adjustments to incorporate STEM education (Bien et al., 2019; To Khuyen et al., 2020; ABD, 2016) demonstrate Vietnam's proactive approach to educational reform.

5.4 *Cultural and Contextual Influences on SEP Distribution*

The contrasts in SEP emphases reveal deeper cultural and systemic factors. Vietnam's competence-based curriculum may inadvertently downplay SEP8 due to its focus on subject-specific competencies, reflecting the challenge of balancing general and specific competencies in a content-rich curriculum. Thailand's limited emphasis on "engaging in argument from evidence" (SEP7) might reflect cultural values that prioritize harmony and consensus over debate, possibly stemming from Buddhist influences and traditional hierarchical structures (Lan & Tien, 2019).

These findings underscore the critical importance of considering cultural and contextual factors in science curriculum design and implementation (Chang, et al., 2018; Roehrig et al., 2007; McFadden & Roehrig, 2020). Successful STEM integration requires a deep understanding of local cultural values, alignment of educational goals with national development objectives, and careful balancing of traditional strengths with global economic demands.

5.5 *Implications for Culturally Responsive STEM Education*

While acknowledging the limitations of our comparative study, including its interpretative nature, we believe this research provides valuable baseline data for understanding the relationships between local and global factors in curriculum development, as recommended by Spratt and Coxon (2020). Future research should explore the long-term impacts of these different SEP emphases on student outcomes, the role of teacher training in implementing culturally responsive STEM education, and the potential for cross-cultural learning between countries.

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Ethical Consideration

The data reported in this study does not require human subjects' approval.

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