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The scientist's ways in national science curricula: A comparative study between Taiwan and Vietnam

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Abstract

Recent science education reforms center at having students learn the practices of scientists. In this study, we aim at exploring how science curricular documents reflect the latest updates from the "practice turn" reform. To do that, we utilize the notion of the scientist's ways of doing science as a perspective to observe the distribution of components constituting scientific practices in national science curricula. Current literature provides several curriculum analysis frameworks based on taxonomies of cognitive demands or international tests. Still, those frameworks are either not intended for science curricula or limited in indicators and hence failed to capture an updating picture of science curricula that reflect the recent practice turn. We employ multiple case study research design and qualitative content analysis approach to compare learning outcomes in Taiwan and Vietnam's two national science curricula. Results from this study offer maps of scientific practices across curricular documents and relevant suggestions for stakeholders to improve science curricula. The study opens a new direction on researching science curricula to make science learning approaching the scientist's ways in reality.

Keywords: learning outcomes, science curriculum, scientific & engineering practices, comparison studies, curriculum analysis

INTRODUCTION

Equipping basic scientific literacy for future citizens (DeBoer, 2011) is indispensable nowadays as science is essential in combating current shared and complex global issues (World Meteorological Organization, 2020). A shift in science education's goals happened throughout the world in which children are expected to become scientifically literate decision-makers (Duschl & Grandy, 2012; Ministry of Education [New Zealand], 2014; National Academy for Educational Research [NAER], 2018; National Research Council [NRC], 2012). Scientific literacy will not be achieved by separating knowledge into fragments and having students learn those chunks (Duschl & Grandy, 2012; Glynn et al., 1991) but by 'giving students a sense of the connectedness of science ideas and having the inclination to link ideas together and apply them to the situation at hand' (Kali et al., 2008, p. 2).

Science education reforms worldwide have been concerned with systemic approaches to equip students with a bigger science picture to achieve this vision (DeBoer, 1991). Those reforms had been moving from merely rote learning about scientific ideas or rote performing scientific actions to engaging in purposefully knowledge building work through meaningful scientific

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Contribution to the literature

- This study provides an analysis framework for science curricular documents which is closely based on practices of scientists in reality.
- This study provides suggestions for science curriculum studies in terms of connecting statement syntax analysis with other analytical backgrounds to see if a learning performance is scientific.
- This study articulates the origin of the recent practice turn in science education and shed a light on how recently released national science curricula are updating with it.

practices (Duschl & Grandy, 2012). Researchers recognized a need for science curricula emphasizing fostering students' expertise in linking scientific concepts and ideas with practices (Pea & Collins, 2008). However, there is a lack of curriculum studies that reflect this global movement in science education. Many national science curricula have been released recently (Ministry of Education and Training [Vietnam] [MOET], 2018; NAER, 2018) but only a few analyses focus on this 'practice turn' in science education (Chabalengula & Mumba, 2017; Qablan, 2018). Therefore, we propose a study to analyze and compare recently released Vietnam's general science education curriculum and Taiwan's general curriculum guidelines in terms of scientific practices.

'Practice Turn' in Science Education

The word 'practice' means as either 'actually doing something' or 'training in something till one becomes familiar and proficient' does not correctly reflect this paper's notion. What we mean by using 'practices' is that those are common socially recognized performances, consisting of experiences, tools, or methods of addressing typical problems of professionals (Gee, 2014; Stern, 2003; Wenger, 1999). To ensure understanding of the term, we must review its historical origin in science education.

There are two major schools of thought about learning: 'acquisitionist' and 'participationist' (Sfard, 1998). The former is knowledge acquisition involving cognitive learning theory. It considers that learning goal is to develop the complexity of acquired concepts in learners' minds (Ausubel et al., 1978). Learners are expected to receive those structures transferred from their teachers. On the other hand, 'participationist' is a metaphor for learning as participation, involving sociocultural learning theory. A learner is considered a part of a bigger community of learners (Lave & Wenger, 1991). Individual learning is not independent of social-cultural context but closely intertwines with and contributes to this community of learners (Packer, 2001). This perspective emphasizes on common specialized activities, where learners participate in. These accepted activities in a particular community are called norms or practices (Wenger, 2011). In short, scientific practices are the scientist' ways of doing science.

The 'practice turn' in science education (Berland et al., 2016; Stern, 2003) is where researchers shared similar arguments: to develop and promote coherent, inter-related understandings of core scientific ideas, students need to engage in common practices in science in schools (Duschl et al., 2007) rather than just learning about the results of those practices (Osborne, 2014). Often, science curricular documents include learning content and learning performances (LPs) as statements expressing learning outcomes that we expect students to achieve. When utilizing the perspective of scientific practices to look at curricula, we could assess if the included activities are scientific and distinguish them from normal learning activity (Ford & Forman, 2006).

Curriculum Analysis from Perspective of Scientific Practices

There are many types of educational curricula (Adamson & Morris, 2014) but in this current study, 'curriculum' refers to national standards. Previously, science curriculum studies have been carried out by using some analytical frameworks. For example, revised Bloom's taxonomy (Anderson et al., 2001) is often used by curriculum researchers (Lee et al., 2015; Wei & Ou, 2018; Yaz & Kurnaz, 2020). This framework enables those studies to offer analysis about knowledge types and cognitive processes levels in curricula. However, its list of verbs and dimensions is not specialized for science education. Hence, it might not be able to observe scientific practices in science curricula (Tekkumru-Kisa et al., 2015). Other studies have used science-related frameworks of international standardized tests like PISA (Sothayapetch et al., 2013) to compare national curricula, however, it only covers a few practices of scientists.

Recently, the set of scientists and engineers' practices (SEPs) synthesized by NRC (2012) have been known more for curriculum studies. Alonzo (2013) compared components of each practice with large-scale assessments to see if those high-stakes tests align with science learning. Lertdechapat and Faikhamta (2018) adapted the list of SEPs (NRC, 2012) into a 32-indicator framework to analyze the Thai primary science curriculum. Molina et al. (2021) used SEPs as one component to examine how Taiwan and Colombia approach quality education goals. However, these studies have not explored if investigated curricular documents reflect the 'practice turn' by connecting scientific knowledge with SEPs or procedural knowledge with science's nature (Berland et al., 2016; Ford, 2015; Osborne, 2014). This study will investigate into this intersection by adapting SEPs into a concrete analytical framework for LPs in curricular documents.

Conceptualization of Learning Performances in Terms of Scientific Practices & Statement Syntax

LPs are behavioral learning outcomes. We expect students to perform some observable activities to make sure that they achieve the outcomes. Statements that are LPs often start with an illustrative and operational verbs so that they could be observable and measurable (Meda & Swart, 2018). LPs are distinguished from learning content, which is knowledge that students learn. Statements that are learning content do not necessarily start with a verb. Here is an example statement for an LP: "ask questions about the natural world" (MOET, 2018). Here is an example statement for a learning content: "the nature world (including biotic and abiotic) is made up of different substances" (NAER, 2018). In short, a scientific practices-based LP is an act of activity that can be evaluated in quality during learning process as a part of scientific practices (Ford, 2015).

Most LPs statements in the two curricula are written in the syntax of complex sentences with multiple clauses. Since verbs are the center of an LP on which instructions and assessments could follow, they are expected to be operational that the cognitive and psycho-motor acts they describe could be directly observed and subjected to judgment (Adelman, 2015). Each LP includes an operational verb describing observable actions, which goes with nominal objects as science content. For example, this LP 'ask questions about the natural world' and 'ask questions about the human-built world' are divided into two parts. One is the main group of words 'ask questions about,' where 'ask' is an operational and illustrative verb. The rest are the two nominal objects, 'the natural world' and 'the human build world'. The phrase 'ask questions about' is considered a sub-SEP, which belongs to SEP 'asking questions and defining problems.' This observation of syntax is the basis to develop our codebook, the means for comparison, in addition to the theoretical foundation of the study.

THEORETICAL FRAMEWORK

Rouse (2007) articulated three features of a social practice and Ford (2015) explained the ideas in the particular context of science education by set forth the conditions at which a performance constitutes a scientific practice. First, a performance of a scientific practice is not independent but relates with other performances within that practice or across other practices. This means in science learning, when students perform an action in relation to other actions, it is considered a part of a scientific practice. Second, the quality of a performance and interactions among performances are evaluated and critiqued aiming at one outcome: the ability to explain nature. Participating in a scientific practice requires students to understand how to enact a performance, to actually do it right, and to judge how these performances work together in explaining nature. Finally, the evaluations and critiques of performances and the interactions of performances are tentatively driven towards improvements in explaining nature. In other words, to participate in a performance that constitutes a scientific practice, students need to know what to do and how to do based on tentatively evaluating to know why doing it.

Table 1. A set of SEP synthesized by NRC (2012)

SEP	Short description
Asking questions & defining problems	Questioning
Developing & using models	Modeling
Planning & conducting investigations	Investigating
Analyzing & interpreting data	Analyzing
Using mathematics & computational thinking	Computation
Constructing explanations & designing solutions	Explaining
Engaging in arguments from evidence	Argumentation
Obtaining, evaluating, & communicating information	Communicating

Based on these features, we suggest two conditions on which we decide if one LP does not belong to a scientific practice. A non-practice LP (or non-SEP) is an LP that either (1) starts with a non-operational and non-illustrative verb, or (2) starts with an operational verb followed by nominal objects with the underlying meaning focuses mainly on science content or discrete action. For example: this statement 'state a definition of an acid' is a case (2) of non-practice LP. In this study, we would consider both types of LPs to explore the reason for their appearances.

Scientific communities might have many practices, and there are multiple ways to choose which ones should be taught in K-12 science education (Stroupe, 2015). Framework for K-12 science education (NRC, 2012) reviewed a set of scientific and engineering practices that stems from the 'practice turn' in science education. Since the practices of scientists and engineers are intertwined, we decided to adapt the framework and rephrased as mentioned in **Table 1**. Also, it is worthwhile to emphasize once again that, as mentioned in the theoretical foundation of this study, we adapt SEPs from NRC (2012) as a mean for comparing curricula not because it is popular or originates from the US. We chose this perspective because it could reflect if national curricula have been updating with the 'practice turn' of the global movement of science education.

The research questions of this study are:

1. How do SEPs appear in the dimensional organizations of LPs of Taiwan's and Vietnam's science curricula?
2. What are the similarities and differences in the appearance and distribution of SEPs in LPs in the two science curricula?

RECENT CONTEXTS OF SCIENCE EDUCATION IN TAIWAN & VIETNAM

The rationales for choosing Taiwan's and Vietnam's curricula to analyze and compare are similarities in geographic location, cultural and educational background, and science education context. First, the two countries are located in the Asia Pacific area and in the past had been under the influence of Confucian culture (Hằng et al., 2015). Confucianism-influenced science education is largely based on factual content knowledge in textbook and does not emphasize on hands-on activities or practices (Hằng et al., 2015). It seems that the two countries' science education shared similar starting points, where science learners were indeed 'acquisitionists', which is a point to reflect upon later. Second, the two countries have similar time releasing the latest science curricula, which might update their latest visions, goals, and methods for science education. We wonder, where their science education is standing now. The current analysis would inspect the ongoing progression of the two countries to see how far from their situation to the global trends of science education.

Concerning these precedents, we propose a study to analyze and compare Taiwan's and Vietnam's intended science curricula from grades 7th to 9th. We chose this scope due to the difference of organization in curricular documents mentioned below.

Taiwan's Context for Latest Curriculum Guidelines

Taiwan's Ministry of Education released national curriculum guidelines for natural sciences (NAER, 2018) and started implementing it in 2019-2020. The document is one result of recent educational reforms (Chiu, 2007). It provides general guidelines instead of a detailed standard as it is expected to create more room for schools and teachers to design school-based curricula with local resources (Chen & Huang, 2017). The guideline arranges learning content according to topics instead of subjects and LPs according to dimensions for each learning stage. In five learning stages in the 1-12 national curriculum, students start learning science from the 2nd to the 5th stage. The scope of the present study focuses on the 4th learning stage, including grades 7 to 9. The reason for this is to ensure the compatibility with the counter document in this research. It has three dimensions including smaller corresponding sub-dimensions. **Table 2** presents Taiwan's organization of dimension of LP.

Table 2. Organization of learning outcomes in Taiwan's curriculum guidelines

Dimension	Sub-dimension
Scientific cognition	
Inquiry ability - Thinking ability	Imagination & creativity Reasoning & argumentation Critical thinking Construction of models
Inquiry ability - Problem-solving ability	Observing & identifying Planning & executing Analyzing & finding Discussing & communicating
Attitude toward science	Cultivate an interest in scientific inquiry
Attitude toward nature of science	Develop habit of applying scientific thinking & inquiry Understanding nature of science

Vietnam's Educational Context

Vietnam's Ministry of Education and Training implemented general education curriculum (MOET, 2018) in the 2020-2021 school year. From grades 1-9, there are three science curriculum documents. This research would focus on the curriculum for grades 7th to 9th. From grades 1-9, there are three science curriculum documents for three science subjects divided as following: nature and society for grades 1-3, science for grades 4-5, and natural sciences for grades 6-9. Each document for each band grade and a particular grade has different goals and expected learning outcomes for science subject matters. The common goals of science education in Vietnam vary from grade 1-9. From grades 7th to 9th, the subject needs to form and develop students' scientific worldview, and help students meet the requirements of providing young human resources for the nation (MOET, 2018). Three components of natural scientific competence in the curriculum are presented in **Table 3**.

Table 3. Framework of learning performances in Vietnam's curriculum

Dimension	Sub-dimension
Natural scientific cognition	
Inquiry about nature	Ask questions related to problem Proposing hypothesis Planning Conducting plan Writing, presenting reports, & discussing Making decisions & suggesting opinion
Apply learned knowledge & skills	

METHODOLOGY

Research Design

We employed a multiple-case study research design (Yin, 2014), which would benefit in-depth analysis within each curriculum and capture similarities and differences. Since the research subjects are the curricular documents, we used content analysis method (Cohen et al., 2011; Krippendorff, 2004) to describe the characteristics and patterns from curriculum materials into fewer categories based on coding rules (Stemler, 2001).

Data Sources and Units of Analysis

Structures of two curricular documents

Both documents present learning requirements, consisting of science learning contents and LPs that students are expected to demonstrate after finishing a learning period. To compare against SEP, only LPs are suitable.

One structural difference is LP's positions. Taiwan's curriculum separates learning contents (e.g., 'the natural world is made up of different substances') and LPs (e.g., 'students can observe the patterns of daily life phenomena). Vietnam's document has two parts where LPs are presented: general LPs, given by natural science competencies' definitions, and detailed LPs divided for each grade. LPs and learning contents are intertwined (e.g., 'conduct an experiment to determine why an object has its shadow.'). Therefore, we would break a Vietnam's learning objective into two parts, LP (e.g., 'conduct an experiment') and learning content (e.g., 'an object has its shadow'). LP would be the focus while learning content was for supporting. **Table 4** shows structural difference of the two curricular documents and ratio of translation.

Unit of analysis

A segmenting step is needed to identify non-overlapping units of analysis (Bernard & Ryan, 1998). An analysis unit is one smallest suitable unit of text that sufficiently represents one LP. Each unit must have a verb or a phrase of verb and one corresponding nominal object. If an LP consists of multiple clauses and verbs, it is separated into different smaller LPs to become a representable analysis unit.

Table 4. Structural difference of two curricular documents & ratio of translation

	Taiwan's curriculum guideline	Vietnam's curricular document	
		General curriculum	Detailed curriculum
Analysis unit	55 units	46 units	589 units
Language medium for analysis	100% English	100% English	30% English & 70% Vietnamese

Language

The language medium of the analysis would be English and Vietnamese. This is due to the significant number of Vietnam's detailed LPs, which limits a full translation. We have methods to ensure the trustworthiness of the coding process, first by ensuring the preciseness of the translation. The whole document of Taiwan was translated into English by a team of Taiwanese science education researchers. Parts of Vietnam's curriculum would be translated into English (**Table 4**). These science education experts, who are familiar with their country's curricular documents as both researchers and teachers, verified both curricula' translated versions.

Establishing Coding Scheme

Two documents are used to develop a concrete codebook. The framework for K-12 science education (NRC, 2012) acts as the backbone, providing a well-defined set of SEPs with respective broad expected LPs. Appendix F of the next generation science standards with a practice matrix would offer more detailed level for coding LPs (NGSS Lead States, 2013). We did not directly use Appendix F of the Next Generation Science Standards to conduct coding due to a large ratio of overlapping SEP descriptions. Therefore, we would build our own codebook with these two documents as references.

To start, we read through two documents and picked out LPs for each SEP. An LP in these documents is a sentence describing students' capability of performing specific actions. After collecting related LP of a SEP, we broke overarching LPs into the smallest meaningful LPs and assigned a numerical code for each. Gathering all three-level codes (i.e., SEP, sub-SEP, and sub-sub-SEP), we would have a concrete codebook, which would be referred to when needed. We continued simplifying the codebook into a simpler coding scheme with a description for each sub-SEP. This coding scheme was the means for coding. It has been refined gradually and iteratively during the pilot coding (Bernard & Ryan, 1998). After needed refinements, the final coding scheme consists of nine SEP codes (i.e., eight normal SEP codes and one non-SEP code), and 79 sub-SEP codes.

Trustworthiness: Experts' Opinions, Multiple-Coding Process, and Inter-Coder Reliability

Some solutions are utilized to guarantee the trustworthiness of this study (Cohen et al., 2011). First, there are two coding phases: multiple coding in which multiple coders participate, and single coding in which the first author would code the full data set. Second, meanwhile, both coding scheme and codebook have been reviewed by experts in the field. All experts agreed on their capability to address all research questions.

Multiple-coding process

To ensure the ideas of SEP in LPs across countries being shared, three more coders participated in the multiple coding process with the first author. They are the second and third authors and one Vietnamese science education researcher. This multiple-coding phase consists of training, pilot coding, and measuring inter-coder reliability. The sub-samples were picked covering all categories in two curricula to ensure the diversity of LPs.

Training and pilot coding: Training is needed since the coding process involves latent data features and thus, requires a certain level of coders' interpretation (O'Connor & Joffe, 2020). The training included providing each SEP's definition, discussing some LPs' interpretations, and distinguishing between SEPs and non-SEP codes. It is followed by the pilot coding for 10% of data units. Coders independently conducted marking data using the coding scheme. The coding rules were sentence-by-sentence coding approach with each unit is presented by a code available in the coding scheme for the existence of concepts or similar meanings (Cohen et al., 2011). Reflexive notes and memos during the coding process would be captured for reflection. If any unit could not mark a code in the coding scheme, coders would assign 'non-SEP' with an emerging sub-code.

After pilot coding, problems with code definitions (from the coding scheme) and code interpretations (from coders) appeared. We considered inter-coder reliability as a measurement of the coding scheme's objectivity and a means of improving the analysis (O'Connor & Joffe, 2020). Therefore, after the first coding, one meeting for each country was organized to discuss any code confusion and the coding procedure.

The refinements of the coding scheme: The common problems the four coders encountered were described by Campbell (2013): unitization and discriminant capability. Unitization happens when coders recognize the key portion to code the analysis unit differently. In the official multiple coding, the first author would conduct coding first to solve this problem. We would mark the text segment recognized as relevant by printing it boldly. After finishing, codes were removed, but the bold types were left for others to focus on the same segment in an LP.

To improve the coding scheme's discriminant capability, first, we tried to reduce code count in the coding scheme by joining overlapping codes and rewriting codes' definitions to improve explicitness. Second, we divided the coding scheme into two halves. Four coders then agreed on coding each sub-sample set at least twice, each time with a half-sized coding scheme, to reduce the burden on their working memory (Campbell et al., 2013).

Table 5. Cohen's kappa values of intercoder reliability for coding SEPs & sub-SEPs in Vietnam's & Taiwan's curriculum documents

	Within-country reliability		Cross-country reliability	
	SEP	Sub-SEP	SEP	Sub-SEP
Taiwan	.750 (substantial)	.355 (fair)	.527 (moderate)	.343 (fair)
Vietnam	.736 (substantial)	.602 (moderate)	.750 (substantial)	.574 (moderate)

Inter-coder reliability: After revising, the official independent coding process was conducted. Four coders coded another 10% of the data set from both countries, and then reliabilities were computed (Lee et al., 2015). Within-country intercoder reliability is the agreement from two coders marking data from their country, and cross-country is that for the other state. Using SPSS 23, we computed Cohen's kappa coefficient (Cohen, 1960) to report the coders' agreement (**Table 5**). The inter-coder reliability result with the strength of agreement (Landis & Koch, 1977) is reported in **Table 5**. The reliability for coding SEP is higher than for sub-SEP since the more concrete codes used, the lower the reliability (O'Connor & Joffe, 2020).

Single Coding Process

After needed discussions and refinements from the pilot and multiple coding, the final coding scheme was made ready for the first author to code the rest of the data.

Data Analysis

Analysis and comparison results in answering the research questions were presented in tables and graphs using Microsoft Excel 16. We presented SEP's and sub-SEP's frequencies and the distribution patterns of SEPs in both curricula. Later, we would take a close look at the relationship among sub-SEPs and SEPs. After analyzing each curriculum, a side-by-side comparison was conducted.

RESULTS

Research Question 1: An Overall Snapshot of SEPs from the Dimensional Organization LPs

SEP in Taiwan's natural science curriculum guidelines

Figure 1 shows the distribution of SEP in Taiwan's curriculum by its dimensions. One sub-dimension often includes various kinds of SEPs. For example, LPs under dimension 'reasoning and argumentation' were marked as SEP analyzing, explanation, and argumentation.

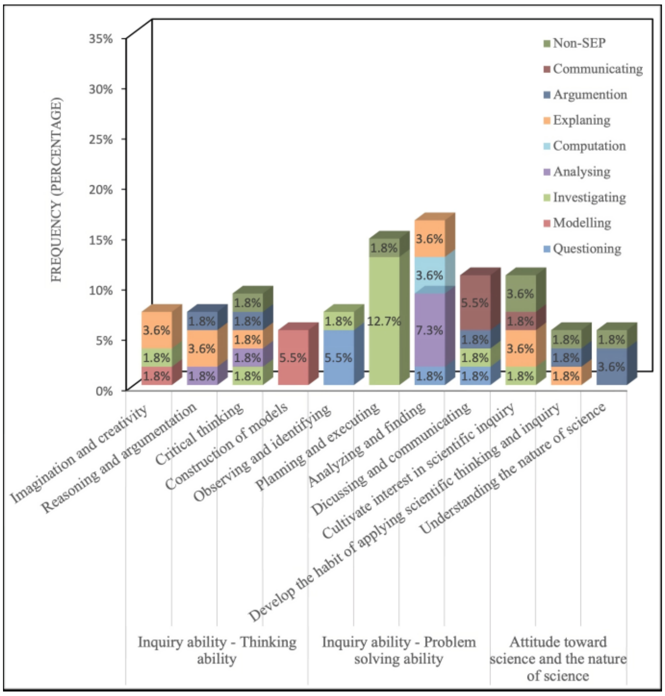


Figure 1. Distribution of SEPs in Taiwan's curriculum (Source: Authors' own elaboration)

Some SEPs under dimension 'problem-solving ability' appear in correspondence with sub-dimensions. For example, most LPs that belong to dimension 'planning and executing' were coded SEP Investigating. LPs, which are under dimension 'attitude toward science and the nature of science' were mostly coded as non-SEP.

SEP in Vietnam's natural science curriculum (general LPs)

SEP distribution of Vietnam's general LPs is presented in a sub-dimensional organization in Figure 2. Each component consists of various kinds of SEPs. 'Inquiry about nature' component has the most LPs. Also, SEP investigating has the highest frequency. Non-SEPs LPs appear mostly in the 'natural scientific cognition' dimension. In 'natural scientific cognition' and 'apply learned knowledge,' non-SEP LPs exist besides SEP ones.

Non-SEP learning performances

In both curricula, there are significant ratios of LPs coded as non-SEP. A non-SEP LP is an LP that either (1) starts with a non-operational verb or (2) starts with an operational verb followed by nominal objects with its underlying meaning focuses mainly on science content or discrete action. The emerging sub-codes for those non-SEP LPs are 'science content,' 'attitude,' 'life-skills,' and 'hands-on.' While most of Taiwan's non-SEP LPs are coded as 'attitude,' that larger portion of Vietnam's non-SEPs is coded 'science content.' Figure 3 is an example of each kind of non-SEP LPs.

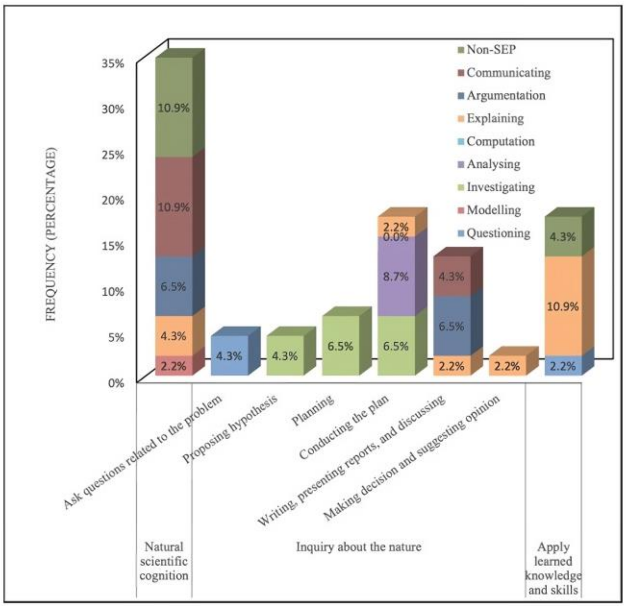
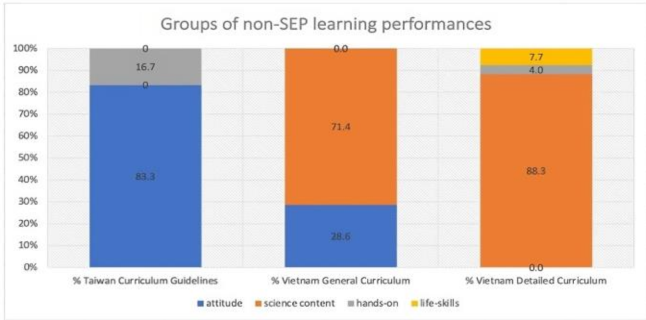


Figure 2. Distribution of SEPs in Vietnam's curriculum (general LPs) (Source: Authors' own elaboration)



Code	Examples of LPs
attitude	'Having appropriate behaviors towards problems related to oneself, family, and community'
science content	'Classify objects, phenomena, and natural processes based on some criteria'
hands-on	'Accurately and safely operate suitable objects, equipment, and resources'
life-skills	'Practice first-aid and bandage for a bond-cracking wounded person'

Figure 3. Frequency of emerging codes in non-SEP (Source: Authors' own elaboration)

Figure 4 shows percentage of SEPs and non-SEPs from Taiwan's and Vietnam's curricula.

Research Question 2: Profile of LPs Under the Perspective of SEPs & Sub-SEPs

Overall profile of LPs in Taiwan & Vietnam according to SEPs

Figure 3 shows the frequencies of each SEP in curricula, and Table 5 shows the numbers of kinds of sub-SEPs in each SEP. All SEPs appear in Taiwan's LPs. SEP Investigating appears the most frequently. Non-SEP

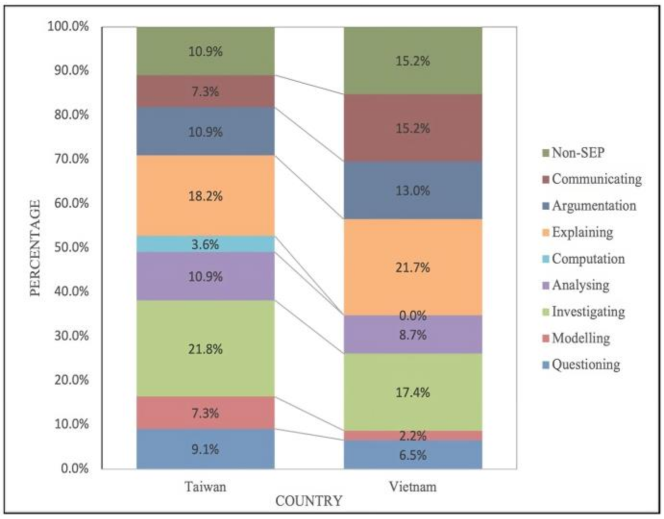


Figure 4. Percentage of SEPs & non-SEPs from Taiwan's & Vietnam's curricula (Source: Authors' own elaboration)

Table 6. Number of kinds sub-SEPs in each SEP

SEP	Number of kinds of sub-SEP	
	Vietnam	Taiwan
Questioning	2	4
Modelling	1	3
Investigating	3	9
Analyzing	4	4
Computation	0	1
Explaining	3	5
Argumentation	5	5
Communicating	5	2
Non-SEP	2	2

LPs hold more than 10% of LPs. SEP investigating has the most diverse sub-SEPs, followed by SEP argumentation and explaining. SEP computation has the lowest frequency with only one kind of sub-SEP.

Seven SEPs appear in Vietnam's general LPs, with SEP computation is missing. SEP explaining, investigating, and communicating are the highest, respectively. SEP communicating and SEP argumentation have various sub-SEPs as opposed to SEP modelling and SEP questioning. Non-SEP LPs account for 15.2% of LPs. **Table 6** shows number of kinds sub-SEPs in each SEP.

SEPs & sub-SEPs in LP of Vietnam's detailed curriculum

The appearance of LPs in detailed curricula in comparison with that of general curriculum is presented in **Figure 5**.

Several characteristics are observed. First, non-SEP LPs occupy more than 40% of all LPs in each grade. Second, some SEPs appear in general LPs but not in detailed LPs and vice versa. For example, SEP questioning and analyzing, which occupy 6.5% and 8.7% of general LPs, respectively, do not appear in specific grades. Alternatively, SEP computation appears in

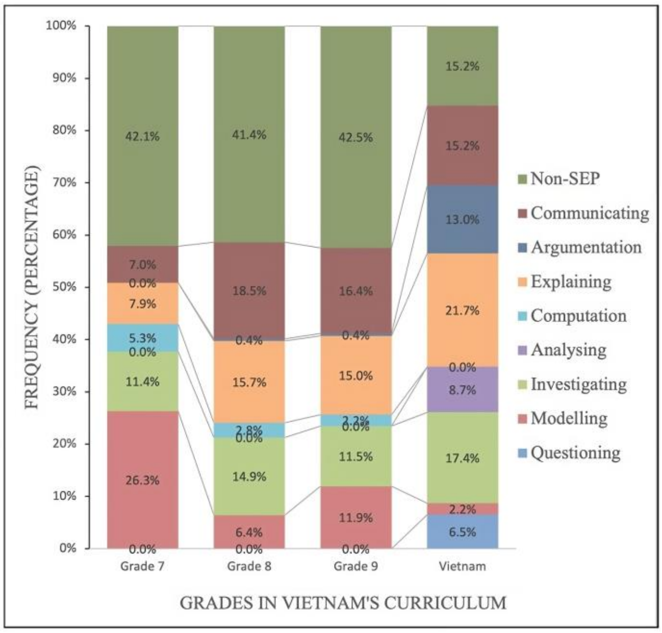


Figure 5. SEPs in detailed LPs in comparison with general LPs in Vietnam's curriculum (Source: Authors' own elaboration)

detailed LPs but not in general LPs. SEP argumentation occupies 13% in general LPs but only holds 0.4% for grades 8 and 9. While SEP modelling LP accounts for 2.2% in general LPs, that in detailed LPs is relatively high.

DISCUSSION

Inquiry-Based Organization of LPs & Correspondence of SEPs

Although curricula seem to organize LPs following the scientific inquiry process, scientists' practices are not linear nor independent but flexible and interrelated, compared to the fixed rules of scientific inquiry (Bell et al., 2012; Ford, 2015). Curricula should guide learning based on what students need to know what to do and how to do it, based on tentatively evaluating and understanding why they are doing it.

As seen in **Table 2** and **Table 3**, LPs in both curricula are organized following the scientific inquiry process (Bybee, 2011). However, SEPs do not seem to correspond with that order. For example, in Taiwan's case, two LPs 'find new questions from received data' and 'offer reasonable questions,' coded as SEP Questioning, appear in sub-dimension 'analyzing and finding' suggesting SEP analyzing. Similarly, in Vietnam's document, within the sub-dimension 'inquiry about the nature' includes a diverse range of SEPs, most of them do not appear in a rigid order but are flexible.

This finding is in harmony with other studies comparing science education through SEPs and scientific inquiry (Bell et al., 2012; Stroupe, 2015). Science education through inquiry has been used to teach scientific reasoning (Abd-El-Khalick et al., 2004; Jin et al., 2016). However, this idea has been challenged. First, researchers emphasize the differences between learning and doing science (Abd-El-Khalick et al., 2004). While doing science is to find new knowledge about existing phenomena about the surrounding world, science education's goal is often perceived as helping students make sense of already well-established and socially accepted scientific content knowledge (Osborne, 2014). Therefore, imitating the major methodology of scientists in science education is not enough.

Second, in actual classrooms, 'inquiry' is often reduced to 'hands-on' and cookbook activities that do not adequately introduce science's nature (Osborne, 2014). In their iterative nature, doing science involve making decisions based on unexpected results at every stage of an investigation (Duschl & Bybee, 2014). Students would understand the uncertain nature and the processes of critiquing, defending, and refining a scientific explanation by actively participating in the explaining practice instead of rote learning a replica explanation (Reiser et al., 2012). Rote following step-by-step activities would not reflect this struggle, but students need to experience balancing both structured and unstructured investigations (Roth, 1994). Osborne (2014) and Ford (2015) suggested that instead of using scientific inquiry alone, the epistemic knowledge of science is needed to be understood as well, even by using other instructional approaches.

Results & Discussion for Profile of Each SEP

The lack of LPs for questioning

Taiwan's SEP Questioning has four kinds of sub-SEPs, that of Vietnam's general LPs is two and no questioning practices in detailed LPs (part a in **Figure 6**). The lack of questioning practices might reflect the tendency for well-establish scientific knowledge to be brought into classrooms and explained to students without giving them needed authority to question (Aguiar et al., 2010; Ford, 2008). Questions drive scientific developments and science education. Questions would pique students' motivation and bring many benefits in science learning, such as identifying and solving cognitive conflicts; improving students' problem-solving abilities and autonomy (Aguiar et al., 2010; Chin & Osborne, 2008). To engage in questioning practices, students need problem-rich environments and chances to ask, distinguish and refine empirical, scientific questions (Osborne, 2014; Roth, 1994).

Modelling practices have been introduced diversely

The two curricular documents introduce modelling practices including various sub-SEPs (part b in **Figure 6**). A similar result of Taiwan was also reflected in Lee and Chiu (2019). Models are simpler representations in many forms of complex objects, phenomena, or theories (Brewer, 2001; Justi & Gilbert, 2002). By engaging in constructing models, students would know which scientific concepts are models and understand scientific knowledge's nature. Evagorou et al. (2015) suggested using visual objects and processes not only as the means to understand scientific content but also as evidence in explaining scientific ideas and science's nature.

However, since a model is often introduced with learning content, students and teachers might have various perceptions. Research shows that many teachers take models not as representations of phenomena but as static facts and seldom invite students to construct or revise models, and many science textbooks do not present the science education meaning of 'model' (Justi & Gilbert, 2002). Therefore, both curricula should have more LPs that require students to distinguish between a model and an actual object (i.e., sub-SEP evaluating models) or to construct and compare different types of models (i.e., sub-SEP Identifying features of models) (Ornek, 2008).

SEP investigating is one of the most frequent SEPs

SEP Investigating accounts for the largest percentage of LPs in Taiwan's and Vietnam's general curriculum (part c in **Figure 6**). This SEP often receives much attention in the field with different terms, such as 'empirical activity,' 'practical work,' 'inquiry tasks,' 'scientific experiment,' and 'laboratory task' (Crujeiras-Pérez & Jiménez-Aleixandre, 2017; Manz et al., 2020). Most general LPs in both documents falling into SEP Investigating were marked as concrete codes, such as 'control variables.' While a large ratio of LPs in Vietnam's detailed LPs was marked as broad codes, such as 'conduct experiment/investigation'. These broad LPs deliver Investigation as a whole and provides little guidance on what teachers and students should do. Researchers have articulated which activities constitute this practice. For example, Duschl and Bybee (2014) proposed a model for unpacking Investigating practices into smaller meaningful activities, providing more guidance for teachers to aid and monitor students experiencing this practice. Since Vietnam's general curriculum already includes many concrete LPs for Investigating practices, we suggest curriculum developers and teachers could combine general and detailed LPs in designing learning activities.

Analyzing practices

In general, both curricula have various sub-SEPs for SEP analyzing, but not in Vietnam's detailed LPs (part d in **Figure 6**). Scientists and engineers need to organize, represent, and interpret collected raw data using different aiding tools (NRC, 2012). Students often struggle to identify salient data patterns and neglect important interpretations (Becker et al., 2017). Roth

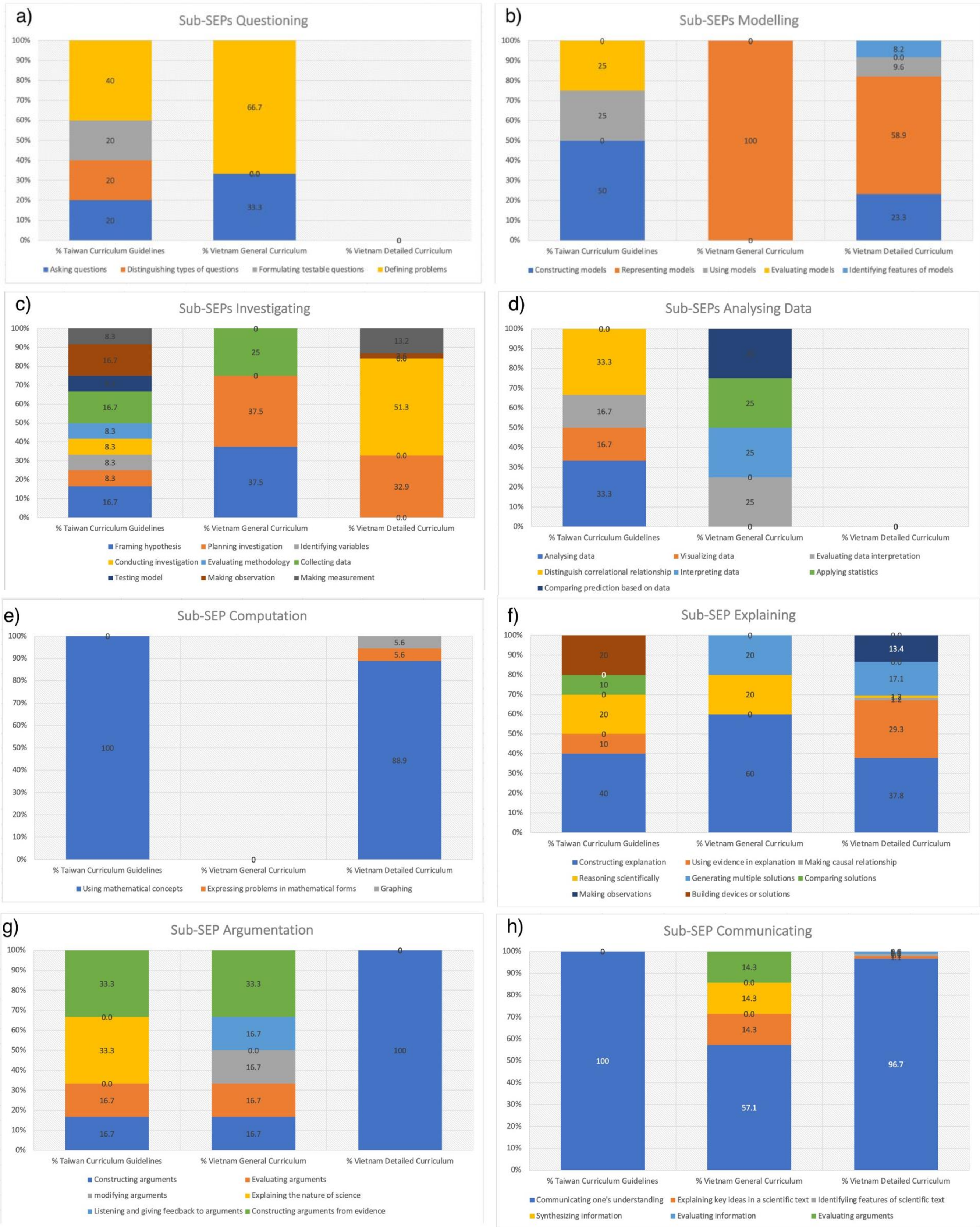


Figure 6. Profile of each sub-SEP appears in two curricular documents (Source: Authors' own elaboration)

(1994) suggested that by analyzing and interpreting data, students could understand the nature of science, iteratively make sense of the investigating process with data, and improve their statistical regression as well as graphing skills.

Lack of computation practices & purpose of mathematics

The mathematical practices hold a small percentage in Taiwan's curriculum (part e in **Figure 6**). Although it is not mentioned in Vietnam's general LPs, the sub-SEPs of computation practices appear in the detailed LPs. The reason might be that computation practices is already nested inside other practices, such as analyzing. Take Taiwan's LP as an example, 'make inferences on the correlation of data.' This LP might involve understanding and using mathematical concepts of functions and processes of statistics.

We also noticed an interesting point. Taiwan's computation LPs are such as 'applying mathematics to formulate explanations.' Vietnam's detailed LPs of this practice mainly involve 'calculating,' such as 'calculate the molecular mass in atomic molecular unit.' Taiwan's LPs include the purposes of mathematics ('to formulate explanation') while Vietnam's ones do not. Mathematics has three functions in science (NRC, 2012): making models more precise, a language of science, and an important structure, where scientific research's logic builds upon. Wilkerson and Fenwick (2017) suggested that mathematics and computational thinking should be taught to achieve scientific understanding. In short, why, and how to use math in science should be emphasized.

Explanation is emphasis on science curricula

Explaining LPs are in the highest percentages, reflecting establishing explanations and solutions in both curricula (part f in **Figure 6**). At the sub-SEP level, the most frequent LPs are sub-SEP Constructing explanations without providing evidence. Sub-SEP LPs that require connecting evidence appear in Taiwan's curriculum and Vietnam's detailed LPs. Establishing an explanation without evidence might be simply reciting facts, while an answer including evidence should be the ultimate aim of science education (McNeill et al., 2006). Students need chance and guidance to explicitly practice establishing a proper scientific explanation (Osborne et al., 2004). Research shows that students involved in establishing explanation with evidence have gained significantly in their content knowledge and ability to transfer learned knowledge into daily life context (Fortus et al., 2005).

Lack of LPs for nature of science

Two sub-SEPs, which explicitly mention science's nature in the coding scheme are sub-SEP explaining the nature of science (part g in **Figure 6**). Taiwan's curriculum has one dimension and a sub-dimension, including the 'nature of science' aspect, matching with the present study's SEP argumentation. This result is in harmony with Yeh et al. (2019) on this matter for Taiwan's curriculum. Vietnam's general LPs introduce various sub-SEPs about arguments but do not explicitly exhibit the 'nature of science' aspect, while detailed LP for argumentation is scarce. Vietnam's result is resonant with other studies showing that curricula often introduce scientific knowledge with a high level of certainty without controversial interpretation (Halliday & Martin, 2003; Yarden, 2009), likely reducing the need for argumentation and understanding science's nature.

Some curricula from other countries and regions around the world have explicitly involved this aspect. They include the epistemological dimension in scientific competencies, having some introductory lessons (e.g., "what is science?", or "how science works?") or encouraging teachers to embed related discussions in classrooms (American Association for the Advancement of Science [AAAS], 1989; Erduran & Dagher, 2014; Waddington et al., 2007). Researchers propose that learning the nature of science would happen in an appropriate context and SEPs (Duschl & Grandy, 2012; OECD, 2019). Students actively participating in the nature of science practices improves their scientific competencies (Tsai, 2015), conceptual change (Tippett, 2009), knowledge integration (Bell & Linn, 2000), and the quality of classroom discourses (Sandoval & Millwood, 2005).

Lack of reading in communicating practices

The vast majority of SEP communicating practices from both countries happens to be coded as sub-SEP 'communicate students' understanding by many types of presentations' (part h in **Figure 6**). Other sub-SEP such as 'describe or explain the supporting evidence in a text' appear less frequently. This phenomenon reveals that much attention in science curricula is paid to communicating, and there is a lack of attention in obtaining, processing, or evaluating input information and the importance of text interpretation in science learning.

Noted the importance of promoting students' participation in practical experiments, Halliday and Martin (2003) also argued it is unnecessary to have students rediscover every knowledge. Researchers suggested using scientific inputs as a beginning for a new investigation for students, and thus, they should be instructed how to read science. The authentic experience of doing science is mainly about ideas or concepts (Osborne, 2019). Therefore, reading first and then writing, talking, or drawing is necessary to understand science fully. Language literacy practices support critical thinking, constructing arguments, or explaining phenomena (NRC, 2014). Bell et al. (2012) recommended that students need chances to encounter different types of scientific texts, comprehend to obtain required information, and evaluate them.

Appearance of non-SEP LPs in curriculum documents: Who are we, 'acquisitionists' or 'participationists'?

Based on the features of SEPs (Ford, 2015; Stroupe, 2015), we defined a non-SEP LP as an LP that either (1) starts with a non-operational verb, or (2) starts with an operational verb following by a nominal object whose underlying meaning focuses mainly on learning content or discrete action. As seen in **Figure 3**, the most common sub-codes that emerged during the coding process that has been assigned for non-SEP LPs are 'science content' and 'attitude.'

Science content LPs: 'Science content' LPs are learning performances that focus exclusively on detailed disciplinary concepts or ideas (Tekkumru-Kisa et al., 2015). An example of such LPs is 'state a definition of an acid,' which hardly falls into any SEP. Both countries' frameworks of LP have one dimension for learning content, namely 'scientific cognition.' 'Science content' LP in Taiwan's results is missing since learning content and LP are separated. However, Vietnam's 'science content' LPs hold a significant ratio. Does Vietnam's curricular documents reflect a philosophy of an 'aquisitionist'?

There are several possible reasons for this appearance. First, operational verbs in LPs are structured based on cognitive demand taxonomy, such as revised Bloom's taxonomy (Anderson et al., 2001). Many curricula's organizing structure has been arranged this way (Lee et al., 2015, 2017; Wei & Ou, 2018). Vietnam's curriculum has a three-cognitive-level framework of LP (i.e., know, understand, and apply), while Taiwan's has six. Second, this might reflect the underlying philosophy with a strong focus on the disciplinary background, that learning science is about learning technical, scientific terms (Halliday & Martin, 2003). This trend could reflect 'acquisitionist' philosophy of the curriculum. Scientific content knowledge is a fundamental part of every science curriculum and textbook. Although this kind of knowledge is important for learners' scientific foundation, that is not science in its entirety (NRC, 2012; OECD, 2016; Zheng & Lee, 2018). Since scientific competence frameworks consist of components other than scientific cognition, detailed learning requirements should integrate all components. One question that curriculum developers and teachers might need to keep in mind when turning to 'participationists': What are the purposes of LPs in a curriculum? To suggest instructional activities, scaffold students' learning, or test students' ability to use technical terms (Schwartz, 2006)? Concerning this matter, there should be an explicit distinction among LPs that scaffold students' thinking and practicing SEPs and those aim at testing students (Halliday & Martin, 2003).

Attitude-related LPs: Both countries' curricula observe the appearance of scientific attitude LP curricula. Attitude is one of the dimensions establishing the frameworks for two curricula. On an international level, scientific attitude has been mentioned in some science educational frameworks, like PISA's competence model (OECD, 2019) or 'habits of mind' (AAAS, 1989). However, attitude is not mentioned in the SEP framework (NRC, 2012), which is understandable that this kind of LP is marked as 'non-SEP.'

Specification of Verbs of LPs

We distinguished detailed and broad sub-SEP codes in the coding scheme to ensure the discriminant capability of two particular codes (O'Connor & Joffe, 2020). However, during coding processes, one problem we called 'umbrella verbs' kept coming back. These are broad phrases of verbs in LPs that could only be marked as broad sub-SEP codes. For example, in Vietnam's document, LP 'conduct an investigation to find out some hereditary disease in the surrounding community' is coded as sub-SEP conducting investigation, accounting for 51% of LPs of SEP investigating. One example in Taiwan's document is 'perceive scientists of different genders, backgrounds, ethnic groups' as non-SEP 'attitude.' Since Taiwan's curriculum guideline is expected to be general, the appearance of broad LPs is understandable (Chen & Huang, 2017). Vietnam's curriculum includes detailed LPs for each grade, which makes this problem worth discussing.

Since verbs are expected to be operational that the cognitive and psycho-motor acts they describe could be directly observed and subjected to judgment (Adelman, 2015). In one example above, the LP requires that students 'conduct an experiment'. We could not be sure what students would do in the experiment. Do students plan how to conduct it or frame a hypothesis? In the other example, how can we know if students perceive the ideas of equality of scientists?

Adelman (2015) suggested some solutions improve LP statements' quality. First, verbs in LP should be chosen thoughtfully to ensure conveying precise meanings. Second, there should be guidance for curriculum developers and teachers in writing LPs. The guidance should indicate the inclusion or exclusion of detailed words and the overall syntax of a qualified LP sentence. Third, the disciplinary operational verbs in scientific and engineering fields are rich and should be utilized in LPs. One popular list of verbs used in general education is revised Bloom's taxonomy (Anderson et al., 2001), which has been pointed out some drawbacks when applied in science education (Tekkumru-Kisa et al., 2015). Researchers recognized a need for science-related vocabulary in writing science curriculum (Lertdechapat & Faikhamta, 2018). Adelman (2015) suggested a list of 20 categories of operational verbs that could be used in writing LPs in science curricula. In summary, this discussion provides the means for curriculum developers from both countries to turn unclear non-SEP LPs into concrete and clear ones.

CONCLUSIONS AND IMPLICATIONS

Conclusions

We would like to acknowledge the roles of this exploratory study in science education curriculum research. The methodology of the study enables us to observe how each curricular document depicts the scientists' way of doing science. First, its results provide a map of scientific practices in LPs' dimensions. We notice the flexibility and interrelatedness of LPs and SEPs compared to the rigid inquiry procedure utilized as the organizational framework in the two curricula. Second, it offers a map of sub-SEPs' frequency inside a SEP. This more detailed map paints a sharp and down-to-activities of scientific practices that are introduced to teachers and students. With this map, researchers, curriculum developers, and teachers can see which practices are diverse and which sub-practices are lacking. Third, besides SEP LPs, the results illustrate a high percentage of non-SEP LPs, like science content and attitude.

From this basis, we observe that although both curricular documents are heading towards 'participationist' philosophy of science learning and join the global 'practice turn', there are still evidence showing that a significant part of curricular documents, especially in Vietnam's case, still stays at 'acquisitionist' strand. Scientists' ways of doing science appear rather too simple and unrealistic. Based on the reflection, top-down adjustments to curriculum documents or bottom-up adjustments in classroom teaching are needed to ensure suitable inclusion of a more diverse scientific practices in science learning.

Practical Implications

As the literature review and theoretical background of the study remind us, introducing realistic scientists' ways diversely into the science curriculum would create more meaningful experiences for students to learn from and practice science themselves. Based on the results, there are some suggestions and practical implications for both countries to do that. First, since Taiwan's curriculum guidelines are expected to be general, schools, curriculum developers, and textbook publishers would use the guidelines to develop their curricula (Chiu, 2007). The distribution of SEPs can aid this process by helping reduce long and broad sentences in curriculum guidelines into small and concrete SEP-based LPs that are easier to include in curricula and textbooks. Second, Vietnam's curriculum developers and teachers can combine general LPs and detailed LPs to have a bigger picture of SEPs in designing science learning activities for actual classrooms. The combination of both kinds of LPs ensures the overarching guidance intertwining with specific concrete LPs. Also, we suggest there should be more LPs for SEP questioning, analyzing, and argumentation, and LPs that belong to the 'nature of science' aspect in Vietnam's curriculum. Mathematics practice-based LPs should include a sense of purpose on why using mathematical processes. Third, both countries can improve their modelling LPs, involve more LPs related to reading and processing scientific texts in the curricula. Finally, non-SEP LPs should be checked to ensure their clarity and specification, significantly helpful for curriculum developers, textbook publishers, and teachers. Some suggestions regard of integrating cognitive demand and SEPs and using appropriate science-and-engineering-related operational verbs in writing science LPs are provided.

Limitations & Future Directions

This research has several shortcomings, which should be addressed with future directions for improvements. First, data, the coding scheme, and the coding process involve reading and interpreting texts that do not have a standard format and syntax with multiple meanings. Texts could only be understood concerning particular contexts, especially in governmental documents like in the present study (Campbell et al., 2013). Given that, this study's results can be used in conjunction with other studies on similar objects with different analysis methods (Fairclough, 2003). Second, the coding process would be largely affected by coders' professional experience and understanding of the curriculum document. Although many researchers do not take this effect as a drawback in this methodology (Fairclough, 2003), some more triangulation methods could be added. Third, we only pay attention to SEP and LPs in curricula. Other studies should investigate other dimensions of a curriculum or alignment among different types of curriculum (Fulmer et al., 2018). Finally, since the present study only focuses on science curricula for grades 7 to 9. Further research could focus on the learning progression of SEPs for both primary and high school curricula to observe the inherence and development of SEPs over time (Duschl, 2019).

Overall, looking from the perspective of SEPs opens new research directions for science curriculum studies. We now know how the two curricula depict science and how they can be improved to make science learning approaching actual scientist' ways through SEPs.

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