Next Generation Science Standards and its Impact to Science Teachers' Development

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Introduction

Science curriculum document or standard is often seen as not only guidance or norm for selecting educational content, teaching and evaluation, but also prospect of science curriculum development. In other word, it illustrates science content and abilities consistently and comprehensively (Bybee, 2014) to promote reform components of current science education system. The Next Generation Science Standards (NGSS) is the curriculum document which introduce contemporary policies for science education in United States. Developed by The National Research Council (NRC), the NGSS was based on the A Framework for K-12 Science Education (K-12 Framework) and aimed at putting the K-12 Framework into practice (NGSS Lead States, 2013). It challenged the traditional approach of how science is taught in the US (Pruitt, 2014; Reiser, 2013) and introduced a new vision of science education (Kang, Donovan, & McCarthy, 2018). In this assignment, the background, componence of NGSS (mainly the 3D learning), and how it would influence teacher's development will be discussed to gain a comprehensive view of the science standard.

The Development of NGSS

As mentioned before, the NGSS was based on the K-12 Framework, which is the first step to create new standards in K-12 science education (NRC, 2012). Pruitt (2014) suggested that the K-12 Framework is a "partner document" to the NGSS, and together they illustrated a landscape of the K-12 science education in the twenty-first century. The goal of the Framework was to embody what K-12 students should know that contribute to their scientific literate in twenty-first century, and a vision of science education that values a learning progression of integrating scientific content with engaging scientific or engineering practices, and the crosscutting ideas that across disciplines of science (NRC, 2012; Pruitt, 2014).

Grounded in the most current research on science and scientific learning and the solid foundation provided by the K-12 Framework, NGSS was developed by a group of 26 lead states and 41 writers to put the framework into a practical stage by summarizing with performance expectations (PEs). Distinct from previous curriculum documents, firstly, the NGSS tend to use science practice to replace science inquiry; Secondly, it articulated a progression of scientific knowledge coherently across K - 12. Moreover, engineering design is added as a componence of science curriculum (Pruitt, 2014).

Three Dimensions of NGSS

The "three-dimensional learning" framework was firstly introduced by the K-12 Framework including disciplinary core ideas (DCIs), scientific and engineering practices (SEPs), and crosscutting concepts (CCCs). The NGSS was based on these three dimensions above, but paid more attention to the integration of DCIs, SEPs and CCCs. Besides, items of three dimensions was integrated by written as performance expectations (NGSS Lead States, 2013) to depict what concept and skills that student should performed.

Dimension 1: Scientific and Engineering Practices (SEPs)

The SEPs (NRC, 2012) were known as "Practices" in NGSS. According to the document (NGSS Lead States, 2013), it employs both science inquiry practices and a set of engineering practices, focusing on practices that scientists investigate and build models and theories about the world and engineers design and build systems. However, that "practice" mentioned before was substantially different from the concept “science inquiry” which used in previous science curriculum documents (McNeill, Lowenhaupt, & Katsh-Singer, 2018). Pruitt (2014) argued that the latter was seen as a science pedagogy rather than a scientific habit of mind, that kept “inquiry” separate from science content standards. Furthermore, science inquiry paid less attention to students’ engagement of construction and critique of knowledge. As a result, students were often asked to use act as scientists to “inquiry” or testing a particular hypothesis rather than using science practices as an approach to explore and explain the natural phenomena (Pruitt, 2014; McNeill, 2018). Besides the critique of the notion science inquiry, NGSS also revealed the social interaction and discourse behind science practices. That is, scientific argument, discourse and work with other scientists are componence of building, testing and refining scientific knowledge, namely, science practices (Reiser, 2013). Therefore, SEPs was built based on the concept “science inquiry” and the notion that science is socially constructed. NRC (2012) framed them in three spheres of activity in Figure 1, showed how science practices embedded in the work of scientists and engineers.

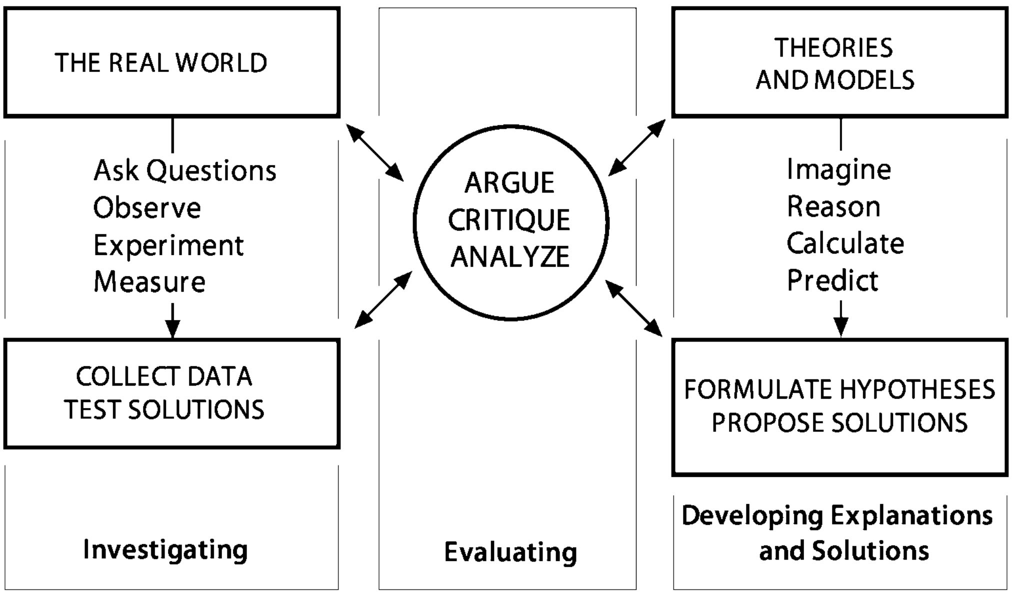

Figure 1. Activities for scientists and engineers. Adapted from NRC (2012, p. 45)

SEPs aimed at not only strengthen students' DCIs and CCCs knowledge of science and engineering. NRC (2012) claimed that the actual "doing of science or engineering" could also support students to get a deeper understanding on how scientific knowledge develops, the nature of science and engineering through practice, and, moreover, to arouse their curiosity and motivation for further science learning. Since students may not capable for complex and professional task that scientists or engineers work with, eight practices were considered as essential for K-12 education by NRC (2012). McNeill, Katsh-Singer, and Pelletier (2015) grouped these practices into three groups (see Table 1):

Table 1. Grouping the eight science practices into investigating, sensemaking, and critiquing.

Investigating Practices	**Sensemaking Practices**	**Critiquing Practices**
1. Asking questions 3. Planning and carrying out investigations 5. Using mathematical and computational thinking	2. Developing and using models 4. Analyzing and interpreting data 6. Constructing explanations	7. Engagement in argument from evidence 8. Obtaining, evaluating, and communicating information

These eight practices above do not isolated work but overlapping and interrelated (Bell et al., 2012). Each practice was involved from kindergarten to high school with different levels in NGSS. Another key component of SEPs that NGSS highlighted besides "science practice" was "engineering practices", which distinguished NGSS from previous curriculum documents (Lederman & Lederman, 2014). According to NGSS,

<u>Dimension 2: Crosscutting Concepts (CCCs)</u>

The CCCs, which was called "unifying concepts" or "common themes" in previous science curriculum documents, are valued concepts that recur frequently in and generalized from science, mathematics and technology. They usually used by scientists for further understand how scientific phenomena happen (Fick, 2018). To clarify the role of CCCs and how CCCs influence students' understandings of phenomena of science, Rivet, Weiser, Lyu, Li, & Rojas-Perilla (2016) suggested four metaphorical perspectives about CCCs, they are: (a)CCCs as Lenses; (b)CCCs as Bridges; (c)CCCs as Tools; and (d)CCCs as Rules of the Game. The first metaphor considered CCCs as lenses for making sense of science phenomena. It enables students to notice features of a phenomenon or problem that they may have ignored previously. By using different CCCs, the approach to analyzing a given situation or problem may be distinct, but all of them are considered as reasonable approach to the scientific reasoning. The second metaphor considered CCCs as bridges that support students to transfer content knowledge across domains and phenomena. CCCs here were hired for understanding conceptual relationships between different phenomena. The third metaphor considered CCCs as tools for students to produce more "sophisticated understandings" (NRC, 2012) and solve practical problems based on and using existing knowledges. The last metaphor considered CCCs as the rule of game. The epistemic "game" means the process that building understanding of science knowledge (Collins & Ferguson, 1993). In this situation, CCCs provide order and structure that students should follow to understand a complex world.

It is clear that all of these four metaphors mentioned above are trying to locate similarities over a unpredictable real word, which indicates CCCs are concepts break the boundary of disciplines and grade levels, to provide students an organizational framework for "connecting knowledge from the various disciplines into a coherent and scientifically based view of the world" (NRC, 2012). Fick (2018) suggested the CCCs could support students in making connections across science ideas and discipline matters, and enhance students' understanding of specific science idea. Thus, seven crosscutting concepts that categorized into three groups was identified for a coherent understanding of science and engineering (NRC, 2012, Table 2):

Table 2. Crosscutting Concepts. Adapted from NRC (2012, p. 84)

Crosscutting Concepts	Descriptions
	Fundamentals to the nature of science
Patterns	Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
Cause and effect: Mechanism and explanation	Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
	Mathematical relationships
Scale, proportion, and quantity	In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.
	Interrelated concepts
Systems and system models	Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
Energy and matter: Flows, cycles, and conservation	Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
Structure and function	The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.
Stability and change	The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.

Dimension 3: Disciplinary Core Ideas (DCIs)

The DCIs are the conceptual knowledge that are fundamental for understanding a specific science discipline. According to NGSS (NGSS Lead State, 2013), DCIs are "a limited set of" concepts which help students to judge and select scientific information which is trustworthy, and get prepared for their future science learning, even scientific research. Therefore, criterions (NRC, 2012) was developed to find core ideas that is truly valued. Specifically, they should:

1. Have broad importance across multiple sciences or engineering disciplines or be a key organizing principle of a single discipline.

2. Provide a key tool for understanding or investigating more complex ideas and solving problems.
3. Relate to the interests and life experiences of students or be connected to societal or personal concerns that require scientific or technological knowledge.
4. Be teachable and learnable over multiple grades at increasing levels of depth and sophistication. That is, the idea can be made accessible to younger students but is broad enough to sustain continued investigation over years.

For each "core idea" must meet at least two of the criteria, and then all DCIs were grouped into 4 major domains: (a) the physical sciences (PS); (b) the life sciences (LS); (c)the earth and space sciences (ESS); and (d)engineering, technology, and applications of science (ETS) (see Appendix) and for each domain there are no more than four DCIs. In addition, should be noticed that boundaries between the four domains above tend to be blurred because scientists nowadays work in interdisciplinary teams more and more frequently (NRC, 2012).

As mentioned earlier, since the NGSS is a coherent standard through kindergarten to grade 12, progression was always emphasized in DCIs. Appendix E of NGSS (NGSS Lead States, 2013) summarized the progression of DCIs on the end of grade-band from the K-12 Framework (NRC, 2012) to demonstrate what and how deep the DCIs that students are able to understand.

<u>Performance Expectations (PEs)</u>

Despite using inquiry, or, science practice, in instruction to support students in learning content is the mainstream opinion that science education community has held and focused on for decades, researchers found that the content knowledge could also promote students' engagement of practice (NRC, 2012). Therefore, in NGSS, three dimensions are not isolate but working together. As mentioned before, one of the “real innovations” (NGSS Lead States, 2013) of NGSS is PEs, which provide students a solid understanding of coherent connections among DCIs, SEPs and CCCs across disciplines. According to Krajcik et al. (2014), the PEs were hired for resolving with the conflicts of learning science content knowledge and engaging in science practice by requiring students to demonstrate their understanding that combined the three dimensions together in practice (NRC, 2012; NGSS Lead States, 2013). Thus, it can be seen that PEs bridged the practice with content, in order to support teaching students using science content, solve scientific problem, do critical thinking and finally make statements based on evidence.

Should be noticed that although PEs provide guidance for what students should learn (NGSS Lead States, 2013), they had no intention to dictate curriculum, which means they were not a “packaged” learning goals nor teaching strategies, but a reference or guidance for teachers and curriculum developers on instruction planning (Krajcik et al., 2014). Besides, PEs were also an assessment tool that students could be assessed on the end of each grade or grade level K-5, grade bands 6–8 (middle school), and grade band 9–12 (high school) to confirm if students are able to apply the knowledge that described in the DCIs and CCCs.

Impact to Primary Science Teachers’ Professional Development (TPD)

To meet the need of the science education for all students in twenty-first century (NGSS Lead State, 2013), NGSS provided a vision of enhance science literacy of public. Bybee (2014) highlighted that NGSS represented a reformation of previous science education approach in the U.S. and will finally improve students’ science achievement. Science education will be affected by NGSS in multiple aspects, including educational system, teacher development and science teacher education. Since teachers are the of science curriculum, understanding how NGSS would impact teachers' professional development (TPD) is important for the implementation of NGSS. (Source Needed)

Thus, a significant change of science education would occur, for instance: shifting from learning facts to exploring natural phenomena through practice; from single and isolated disciplinary knowledge (science itself) to inter-disciplinary ideas that connected with each other (e.g. STEM) etc. (Bybee, 2014).

However, the realization of NGSS could be challenging due to the lack of teaching materials, assessment tools and possible misunderstanding from educators (Pruitt, 2014).

McNill, Lowenhaupt, and Katsh-Singer (2018) also addressed that the school leaders may influence the implication of NGSS due to their understanding of science instruction.

Hence, besides supporting all educators to grasp the idea of NGSS, a simplified version may employed for stakeholders with limited background in science (McNill, 2018).

<u>Apply NGSS to the Classroom</u>

<u>Engineering Practices</u>

Researchers found that teachers know little about engineering due to a lack of preparation during their pre-service education in the US (Duncan, Diefes-Dux, & Gentry, 2011; Cunningham, 2009).

In China? In Macau?

To solve this issue, teacher professional development is necessary because teachers can have an opportunity to fill the gap in their knowledge and instruction on the new contents (Darling-Hammond, 1996; Desimone, 2009). Therefore, TPD in engineering for in-service teachers becomes essential to enrich their STEM and pedagogical content knowledge (PCK) and to improve teacher practices, so they can be successful at teaching engineering (Sun & Strobel, 2013; Yoon, Diefes-Dux, & Strobel, 2013).

What else?

Conclusion

With the integrated three dimensions: SEPs, CCCs and DCIs, NGSS generates a new prospect for science education. Science and engineering practices enables students to discovery the natural world and build their knowledge; Boundaries of disciplines are blurred, and connections are made across scientific knowledges and concepts. The NGSS and other curriculum document may also inspire elementary science education and teachers' education in Macau, which is needed for further study.

Appendix

Disciplinary Core Ideas (NRC, 2012)

1. **Physical Sciences**
   - PS1: Matter and Its Interactions
     - PS1.A: Structure and Properties of Matter
     - PS1.B: Chemical Reactions
     - PS1.C: Nuclear Processes
   - PS2: Motion and Stability: Forces and Interactions
     - PS2.A: Forces and Motion
     - PS2.B: Types of Interactions
     - PS2.C: Stability and Instability in Physical Systems
   - PS3: Energy
     - PS3.A: Definitions of Energy
     - PS3.B: Conservation of Energy and Energy Transfer
     - PS3.C: Relationship Between Energy and Forces
     - PS3.D: Energy in Chemical Processes and Everyday Life
   - PS4: Waves and Their Applications in Technologies for Information Transfer
     - PS4.A: Wave Properties
     - PS4.B: Electromagnetic Radiation
     - PS4.C: Information Technologies and Instrumentation
2. **Life Sciences**
   - LS1: From Molecules to Organisms: Structures and Processes
     - LS1.A: Structure and Function
     - LS1.B: Growth and Development of Organisms
     - LS1.C: Organization for Matter and Energy Flow in Organisms
     - LS1.D: Information Processing
   - LS2: Ecosystems: Interactions, Energy, and Dynamics
     - LS2.A: Interdependent Relationships in Ecosystems
     - LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
     - LS2.C: Ecosystem Dynamics, Functioning, and Resilience
     - LS2.D: Social Interactions and Group Behavior
   - LS3: Heredity: Inheritance and Variation of Traits
     - LS3.A: Inheritance of Traits
     - LS3.B: Variation of Traits
   - LS4: Biological Evolution: Unity and Diversity
     - LS4.A: Evidence of Common Ancestry and Diversity
     - LS4.B: Natural Selection
     - LS4.C: Adaptation
     - LS4.D: Biodiversity and Humans

3. **Earth and Space Sciences**
   ESS1: Earth's Place in the Universe
      ESS1.A: The Universe and Its Stars
      ESS1.B: Earth and the Solar System
      ESS1.C: The History of Planet Earth
   ESS2: Earth's Systems
      ESS2.A: Earth Materials and Systems
      ESS2.B: Plate Tectonics and Large-Scale System Interactions
      ESS2.C: The Roles of Water in Earth's Surface Processes
      ESS2.D: Weather and Climate
      ESS2.E: Biogeology
   ESS3: Earth and Human Activity
      ESS2.A: Earth Materials and Systems
      ESS2.B: Plate Tectonics and Large-Scale System Interactions
      ESS2.C: The Roles of Water in Earth's Surface Processes
      ESS2.D: Weather and Climate
      ESS2.E: Biogeology
4. **Engineering, Technology, and Applications of Sciences**
   ETS1: Engineering Design
      ETS1.A: Defining and Delimiting an Engineering Problem
      ETS1.B: Developing Possible Solutions
      ETS1.B: Developing Possible Solutions
   ETS2: Links Among Engineering, Technology, Science, and Society
      ETS2.A: Interdependence of Science, Engineering, and Technology
      ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World

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