Design for International Standards for Chemistry Education

by Mei-Hung Chiu

Over the past 30 years, Johnstone's (1982, 1993) famous triangle of learning levels (macro, submicro, and representation) has played an influential role in chemistry education. Professional chemists work well inside the triangle and can manipulate all three components simultaneously and efficiently because of their descriptive and functional (macroscopic level), representational (symbolic level), and explanatory (microscopic level) skills. However, it can be a challenge for learners who lack the skill to connect and transform these components to learn chemistry, especially, when they are unfamiliar with these three components and have limited capacity to manipulate them mentally (Johnstone, 2000). Other researchers argue there are limitations to these three levels of teaching and learning chemistry and modified the triplet in chemistry by adding terms (such as experiences, models, visualization in Talanquer, 2011), by emphasizing the interaction between the three components proposed by Johnstones (Taber, 2000, 2013), and by introducing new elements (such as human element by Mahaffy, 2006; native languages by Chiu, 2012).

The purpose of this study was to identify and specify the chemistry literacy that elementary and secondary school students need to develop during their school years (K-12) via analyzing international chemistry curriculum standards across different countries. It aimed to compare the international chemistry curriculums and recommend teaching and assessment materials for researchers, educators, and policy makers. Several existing documents were used as the foundation of the study, for instance, globalization of science education (Chiu, 2012; Chiu & Duit, 2011), findings of TIMSS and PISA outcomes (OECD, 2013), and the chemistry education triangle approach (Johnstone, 1991, 2000; Mahaffy, 2006; Talanquer, 2011). Research has shown that most chemistry teaching focused on the factual knowledge and observable phenomenon. As a result, therefore students are lacking of the competence on bridging the phenomenon at macroscopic level to submicroscopic level. Also, teachers rarely help students build bridges to comfortably move between the three levels, macroscopic, microscopic, and symbolic levels in chemistry education (Talanquer, 2011; Treagust, Chittleborough, & Mamiala, 2003). Therefore, in order to propose International Standards for Chemistry Education (ISCE), several international chemistry education researchers from the IUPAC Committee on Chemistry Education collaborated and analyzed curriculum standards of chemistry education in different countries from grades 1-12 based upon the perspectives of phenomenon (*e.g.,* testable, measurable, and sensible), structure (*e.g.,* atomic and/or molecular models), and symbols (*e.g.,* formulas or icons) in order to make international comparisons.

There is no single curriculum standards set for promoting chemistry education in emerging and developed countries but there are so much to learn from different cultures and societies for improving chemistry education and providing insights for educational reforms in the future.

ISCE Framework—Terms definition

To adopt the relevant research in our study, we used the three epistemological aspects to analyze the standards of chemistry curriculum which include macroscopic, microscopic, and symbolic representations. Each definition of the three categories is stated below:

1. The macroscopic level is the observable chemical phenomena (or via human sensors) that can include experiences from students' everyday lives such as color changes, observing new products being formed and others disappearing. In other words, the characteristics of this aspect are dealt with concrete, observable, operational experience of scientific phenomenon which include descriptive knowledge of chemical phenomena
2. The microscopic level of representations, developed by chemists, which are descriptive, explanatory, and predictive, such as the particulate theory of matter, is used to explain the macroscopic phenomena in terms of the movement of particles such as electrons, molecules, and atoms for explaining macroscopic phenomenon.
3. Symbolic representations: In order to communicate about these macroscopic phenomena and underlying mechanism of the phenomena, chemists commonly use the symbolic representations to describe or explain the relations of components of a system. The symbolic representations include pictorial, algebraic, physical and computational forms such as chemical equations, graphs, reaction mechanisms, analogies and model kits. Symbols for electron, ions, molecules, chemical formula, chemical equations are used.

Coding process

- Step 1: To confirm which grader (ages) do the standards belongs to.
- Step 2: To confirm the national standards according to the contents, practices or application.

The task group at work, from left: Mustafa Sözbilir, Masahiro Kamata, Jan Apotheker, Mei-Hung Chiu, Michael Droescher, and Suzanne Boniface

- Step 3: To use Table of Contents of Atkins' General Chemistry textbook as the key concepts for analysis.
- Step 4: According to the statement of standards to distinguish the three epistemological elements of the framework:
  - Phenomenon (macro): observable, measurable
  - Structure (micro): model, atomic and molecular structure
  - Symbolic (representation)
  (See Figure 1, top)
- Step 5: Meetings for consensus on the coding scheme and then started to code individually
- Step 6: Coded and discussed
- Step 7: Finding examples from local textbooks according to macro/micro/symbolic representation.

Results

The results show that in general, curriculum standards for students' progressive development from phenomena in the lower grades (before 6th grade), to symbolic descriptions linked with the preliminary structures in the middle grades (grades 7-9), and finally to move to in-depth descriptions at the atomic and molecular levels (microscopic) of the structures with symbols at grades 10-12. However, standards for grades 10-12 in senior high schools tend to be decontextualized and focus on chemical theories.

As for emphasis of curriculum standards in different countries, the results show that first, Chile and Turkey had more emphasis on microscopic and symbolic levels and few emphases on the integrations of the three aspects in their curriculum standards. Second, although Japan had the chemistry curriculum standards linking between each two aspects of the triangle elements respectively, there were missing the integrations of the three aspects. Third, as for Malaysia, more emphases of the standards on the use of symbols in chemistry learning and few emphases on the linkage between phenomenon and symbols. Finally, there were three countries showed their curriculum standards integrating the three aspects together, namely, Israel, New Zealand, and Taiwan.

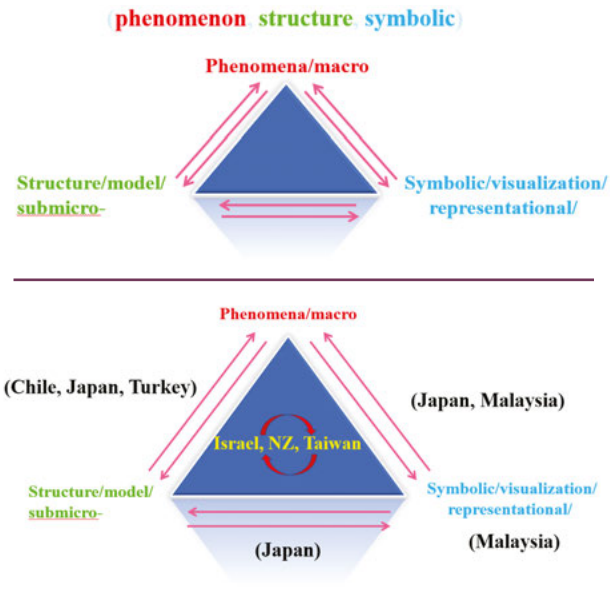

Figure 1: (top) The three epistemological elements used in the coding process. (bottom) Qualitative focus emphasized by specific national curriculum

To summarize, first, Chile, Japan and Turkey emphasized more on the linkage between phenomena at macroscopic level and structures of matters at microscopic level. Second, Japan and Malaysia focused more on the linkage between phenomena at macroscopic level and symbolic representations of matters and compounds, while there were three countries integrating macroscopic, microscopic, and symbols in their curriculum standards to present a relatively holistic framework for chemistry learning (Figure 1, bottom).

Conclusions

With well-designed curriculum standards, teachers can develop appropriate learning materials and strategies to cultivate students' understanding of chemistry and then apply their knowledge of chemistry in problem solving and authentic situations. The analyses of this study might provide an avenue for designing chemistry curriculum standards and further for chemistry education reforms.

We are faced with a great challenge in teaching chemistry, but it is also a great opportunity for us, as chemistry education researchers, to reflect on why we do the work we do and where our research could lead us to the next stage for future generations. While learning chemistry is a challenge for most students, research has shown that certain approaches can effectively promote learning through the use of sense-making materials and strategies (such as modeling-based text, conceptual conflict scenario, systems thinking, and innovative technology). Yet, more evidence-based research is needed to guide us on improving the quality of chemistry education both locally and globally. This goal cannot be easily achieved without researchers' and policymakers' persistence and passion for chemistry education.

Note:

Research findings were presented at various international conferences, such as the 23rd International Conference on Chemistry Education in Toronto, Canada, 2014; International Conference on Network for Inter-Asian Chemistry Educators (NICE) in 2015, and 24th International Conference on Chemistry Education 2016. Some of the participating countries might launch new curriculum standards ever since. Further analysis might be needed to investigate the progressive development on curriculum standards in chemistry across countries.

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References

1. Chiu, M. H. (2012). Localization, regionalization, and globalization of chemistry education, *Australian Journal of Education in Chemistry,* 72, 23-29.
2. Chiu, M. H., & Duit, R. (2011). Editorial: Globalization: Science education from an international perspective. *Journal of Research in Science Teaching,* 48(6), 553-566.
3. Johnstone, A. H. (1982). Macro- and microchemistry. [Notes and correspondence]. *School Science Review,* 64(227), 377-379.
4. Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning,* 7, 75-83
5. Johnstone, A. H. (2000). Chemical education research: Where from here? *University Chemistry Education,* 4(1), 34-38.
6. Mahaffy, P. (2006). Moving chemistry education into 3D: A tetrahedral metaphor for understanding chemistry. *Journal of Chemical Education,* 83(1), 49-55.
7. OECD (2013). Education at glance 2013 indicators. OECD Publishing. http://dx.doi.org/10.1787/eag-2013-en
8. Taber, K. (2013). Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemical Education Research and Practice,* https://doi.org/10.1039/C3RP00012E
9. Talanquer, V. (2011). Macro, submicro, and symbolic: The many faces of the chemistry "triplet". *International Journal of Science Education,* 33(2), 179-195.
10. Treagust, D., Chittleborough, G., & Mamiala, T. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education,* 25(11), 1353-1366.

Capacity Building of Teachers on Chemistry Hands-on Small-scale Experiments in High School in Asia: Nepal

by Supawan Tantayanon, Jyoti Giri, Rajesh Pandit, Rameshwar Adhikari, Supakorn Boonyuen and Zuriati Zakaria

Capacity Building of Teachers on Chemistry Hands-on Small-scale Chemistry [Kathmandu, 19-20 October 2022]: The capacity building of high school government science teachers were envisioned by the IUPAC Committee on Chemistry Education by introducing