Nature of science and chemistry education

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Nature of science (NOS) is widely recognized as one of the key aims of chemistry education. The purpose of this paper is to describe the importance of teaching NOS as well as to discuss the role of NOS in sustainable chemistry education.

Scientific literacy and nature of science

The concept scientific literacy was introduced in the late 1950s. Although it initially focused on improving the public understanding of science and support for science and industrial programs, during the following decades the concept was debated and reconceptualized countless times. During the 1960s and 1970s, the new academic knowledge of science and technology studies deeply challenged the traditional positivist view of science portrayed on curricula and science textbooks. The historical, philosophical and sociological analysis of the scientists' work provided a new view of science as a socially embedded enterprise. Eventually, this new view of science studies had an effect also on school science education. Inspired by the new academic research on science and technology studies as well as environmental and civil rights movements, in the late 1970s and 1980s the social context and science-technology-society (STS) movement began influencing the conceptualizations of scientific literacy. Many teachers were disappointed about the outcomes of traditional science education and wished to promote social awareness in their students. It was suggested that scientific literacy comprises not only of the knowledge about the basic notions of science, but also the understanding of the ethics that control scientists in their work, the interrelationships of science and society, and the differences between science and technology. In the past three decades STS movement–and its derivatives such as the socio-scientific issues approach–connected scientific literacy with global problems on ecological, social and economic sustainability such as climate change (Vesterinen, Manassero-Mas & Vázquez-Alonso, 2014).

During the recent decades, scientific literacy has become a central educational objective of science education worldwide and it is often used as an umbrella term covering most aims of science education. Researchers and policymakers justify the need for scientific literacy on variety of rationales, such as usefulness of scientific knowledge for everyday life, learning transferable skills for problem solving, personal autonomy on science related issues, decision making as consumers, democratic participation in political issues related to science, ethical responsibility of scientists, politicians, and citizens, supporting sustainable development, as well as transmission of culture of science as an integral part of our cultural heritage (Laugksch, 2000). Whatever the rationales behind them, most conceptualizations of scientific literacy seem to agree that one central element of scientific literacy is to understand what science is, how it works, how it relates to technology and society, and how scientists operate (Hodson 2008).

Within science education, suitable educational answers to these questions have been described by various characterizations of nature of science (NOS). As a crucial element of scientific literacy, NOS is now widely recognized to be a key concept in the curricular aims of science education all over the world.

Nature of chemistry

NOS is a very complex concept, partly because it evolves and changes as our understanding of science and science itself evolves and changes. It brings together a variety of aspects coming from different disciplines, such as history, philosophy, sociology and psychology. Although there might not be a general agreement on the exact definition of NOS, there seems to be some sort of consensus regarding the central features of NOS that should be covered in science education (see e.g. Lederman 2007). On the whole, the educational consensus on NOS refers to basic and relevant NOS features while keeping them highly uncontroversial: what is science; and the methods science uses to construct, develop, validate and disseminate the knowledge it produces; the features, activities and values of the scientific community; and the internal and external links of science, such as the links between science, technology and society. The most striking aspect of the consensual NOS features, which in turn provide further evidence in support to the teaching of NOS in schools, is the strong similarity amongst the different lists that researchers have proposed.

Traditionally, philosophy of science as well as NOS has concentrated on "what is viewed as the paradigm science, that is to say physics" (Scerri 2001, p. 165). Since the more naturalistic accounts of science began dominating the fields of academic science studies during the last thirty years, philosophers of science have turned their attention also towards other scientific disciplines such as chemistry. As there are cultural, methodological and epistemological differences between the different domains of science, there is also a need for more context specific descriptions of NOS. Based on the previous descriptions of central aspects of NOS, domain-specific research on philosophy of chemistry and chemical education, and analysis of local curricula and textbooks I described seven features characterizing the nature of chemistry (Vesterinen, Aksela & Lavonen, 2011):

1. Tentative: Even though some categories of knowledge are more durable, scientific knowledge is never absolute or certain. Models and theories used in chemistry as well as the ways of doing research have changed throughout history and are still subject to change.
2. Empirical: Although science is not rigid and uses several methods in creating knowledge, scientific claims are derived from observations of natural phenomena. Observations about chemical phenomena are often, but not always, obtained through experimentation.
3. Model-based: In chemistry, models representing certain aspects of the world are used as a way to explain phenomena. As we move from macroscopic to microscopic and

submicroscopic 'realities', the models need more and more idealizations. Hence, chemical models cannot be all-inclusive presentations of the world or faithful copies of reality, and are always level specific and limited in their scope.

4. Inferential: In creation of models, one has to take into account that chemical phenomena happening on submicroscopic level are not directly accessible to senses. Models in chemistry are thus inferential, in the sense they can only be measured through effects, and scientists use creativity in inventing explanations for and descriptions of the phenomena.
5. Technological products: Chemistry is not only interested in the properties of molecules, but also in generating new substances and refining the processes of production.
6. Instrumentation: Direct observation of phenomena usually happens at a level unattainable to our perception, and phenomena are accessed through the window of technology, with instruments specially designed towards refining our current scientific models. Technology plays a huge role in the process of creating chemical knowledge, as instruments, experimental settings, and objects of research are all created by scientists.
7. Social and societal dimensions: Science is inherently human enterprise. Chemistry is practiced in the context of a larger cultural environment and scientific knowledge is produced in a social setting. The acceptable research methods and results are socially negotiated. As science is not done outside society, also societal needs and support in the form of norms, legislation, and funding affect the way chemistry is practiced. The cooperation inside and between research groups, review process of scientific journals, scientific conferences and institutions, the division of science into various scientific disciplines, as well as research done for practical or commercial purposes are all aspects of these dimensions of chemistry.

Of course, the list of central dimensions of nature of chemistry presented here should not be seen as conclusive, as there are probably numerous other features of science, which could be discussed during chemistry education. The features described should be regarded more as themes of discussion rather than 'the truths' of nature of chemistry to be memorized.

Nature of chemisty and technoscience

Of all the sciences, chemistry is perhaps most closely related to industry and technology (e.g. Schummer, 1999). In order to cover the enormous complexity of technoscientific systems in contemporary societies and to produce an authentic image of chemistry, there is a need to embrace both science and technology as complementary aspects of chemistry (see Tala & Vesterinen, 2015).

One aspect of technoscientific nature of chemisty is the epistemological and cognitive role of instrumentation in empirical science. Direct observation of chemical phenomena happens at a level unattainable to our perception, and they are accessed through the window of technology, with instruments specially designed towards refining our current scientific models. Technology plays a huge role in the process of creating chemical knowledge, as instruments, experimental settings, and objects of research are all created by scientists. New technology also drives forward scientific practice. The way chemical research is done has always been and still is transformed by technological development of instrumentation (Baird 2000).

Another important technoscientific aspect of nature of chemistry is the fact that chemistry is not only interested in the properties of substances, but also in generating new substances and refining the processes of production. Producing new substances can even be seen as the main activity of chemists. Even basic research in chemistry is not only concerned about explaining the world, but also about the manipulation of matter on a molecular level. Of the thousands of scientific articles in chemistry published every week, most deal with the creation of new substances (Schummer 1999). New substances are not only the products of the research; they are also the subjects of the research. As 19th century chemist Berthelot pointed out: "Chemistry creates its own subject. This creative ability, similar to an art, is the main feature that distinguishes chemistry from the natural and humanitarian sciences" (as cited in Smit, Bochkov & Caple, 1998, p. 28).

In describing the larger cultural milieu, in which chemistry is practiced and new substances are created, we also have to acknowledge how closely chemistry as a science is related to chemical industry. Science and industry seem to have a symbiotic relationship in which chemistry as a science cannot be dissociated from the chemical industry (Laszlo 2006).

Nature of chemistry and education for sustainability

In science education, research and development is often presented as a way to produce knowledge and technologies, benefitting both the environment and the society (e.g. Vesterinen et al., 2009, 2013). However, as risk is an inherent characteristic of the technological society, presenting technology as exclusively beneficial for human beings is not only naïve, but also manipulative and misleading. In order to overcome the environmental challenges that the world is facing, a combination of scientific and technological solutions needs to be combined with political decisions and individuals' sustainable behavior. Therefore, even though chemistry education should address the potential of technological innovations, it also needs to present limitations of technological progress, including societal and economic constraints. It needs to encourage critical debate about technology and the role that industry and consumers have in its development.

As the focus of technology educations is moving from the skills involved in the fabrication of artefacts towards development of critical awareness of the technologically mediated world and the way technology shapes our future (see Dakers, 2006), the chemistry education should also focus more on critical awareness of how chemistry contributes to the causing and solving of social and ecological problems – and how each and every one of us can contribute to solving them through human agency and action (Vesterinen, Tolppanen & Aksela, 2016). Discussion on these topics could also be supported by providing students with opportunities to meet and talk with expert practitioners such as scientists and engineers. Previous research has shown that such encounters can provide students with role models, who may influence how students perceive science, themselves, their future, and active citizenship (Vesterinen & Aksela, 2009).

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References

Baird, D. (2000). Analytical instrumentation and instrumental objectivity. In N. Bhushan, & S. Rosenfeld (Eds.), Of minds and molecules: New philosophical perspectives on chemistry (pp. 90–113). New York, NY: Oxford University Press.

Dakers, J. (2006). Towards a philosophy for technology education. In Dakers, J. (Ed.), Defining technological literacy: Towards an epistemological framework (pp. 145–158). New York, NY: Palgrave.

Hodson, D. (2008). Towards scientific literacy: A teachers' guide to the history, philosophy and sociology of science. Rotterdam: Sense Publishers.

Laszlo, P. (2006). On the self-image of chemists, 1950–2000. HYLE: International Journal for Philosophy of Chemistry, 12, 99–130. Retrieved from: http://hyle.org/journal/issues/12-1/laszlo.htm

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. Science Education, 84, 71–94. http://dx.doi.org/10.1002/(SICI)1098-237X(200001)84:1<71::AID-SCE6>3.0.CO;2-C

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell, & N. G. Lederman (Eds.), Handbook of research on science education (pp. 831-879). Mahwah, NJ: Lawrence Erlbaum Associates.

Scerri, E. R. (2001). The new philosophy of chemistry and its relecanve to chemistry education. Chemistry Education: Research and Practice in Europe, 2, 165–170. http://dx.doi.org/10.1039/B1RP90016A

Schummer, J. (1999). Coping with the growth of chemical knowledge: Challenges for chemistry documentation, education, and working chemists. Educación Química, 10, 92–101. Retrieved from: http://joachimschummer.net/papers/1999_Copingwithgrowth_Educacionquimica.pdf

Smit, W. A., Bochkov, A. F., & Caple, R. (1998). Organic synthesis: The science behind the art. Cambridge: The Royal Society of Chemistry.

Tala, S., & Vesterinen, V.-M. (2015). Nature of science contextualized: Studying nature of science with scientists. Science & Education, 24(4), 435–457. http://dx.doi.org/10.1007/s11191-014-9738-2

Vesterinen, V.-M. & Aksela, M. (2009). A novel course of chemistry as a scientific discipline: how do prospective teachers perceive nature of chemistry through visits to research groups? Chemistry Education Research and Practice, 10(2), 132–141. http://dx.doi.org/10.1039/B908250F

Vesterinen, V.-M., Aksela, M. & Lavonen, J. (2013). Quantitative analysis of representations of nature of science in Nordic upper secondary school textbooks using framework of analysis based on philosophy of chemistry. Science & Education, 22(7), 1839–1855. http://dx.doi.org/10.1007/s11191- 011-9400-1

Vesterinen, V.-M., Aksela, M. & Sundberg, M. R. (2009). Nature of Chemistry in the National Frame Curricula for Upper Secondary Education in Finland, Norway and Sweden. NorDiNa: Nordic Studies in Science Education, 5(2), 200–212. Retrieved from: http://www.journals.uio.no/index.php/nordina/article/view/351

Vesterinen, V.-M., Manassero-Mas, M.-A. & Vázquez-Alonso, Á. (2014). History, philosophy, and sociology of science and science-technology-society traditions in science education: Continuities and discontinuities. In M. R. Matthews (Ed.), International handbook of research in history, philosophy and science teaching (pp. 1895–1925). Dordrecht: Springer. http://dx.doi.org/10.1007/978-94-007- 7654-8_58

Vesterinen, V.-M., Tolppanen, S. & Aksela, M. (2016). Toward citizenship science education: what students do to make the world a better place? International Journal of Science Education, 38(1), 30– 50. http://dx.doi.org/10.1080/09500693.2015.1125035