SOLO taxonomy supporting practical chemistry instruction

Päivi Tomperi

This article is based on a doctoral dissertation (Tomperi, 2015) which examines the design and development process of a STEM professional training course implementing SOLO taxonomy. SOLO taxonomy provides a common language for teachers to construct knowledge collaboratively. In the created research-based training model the modification of laboratory assignments in chemistry books into inquiry tasks using SOLO taxonomy preceded the enactment phase in the classroom. According to research, it is well known that a conceptual change will not take place until teachers practice new teaching strategies and experience how the created new material supports student learning.

The nature of science and chemical literacy are nowadays included in the curricula worldwide emphasizing the experimental nature of chemistry but, in practice, it is often left to teachers to plan by themselves how to carry out practical work meaningfully. In order to support teachers to design modern learning environments in chemistry, in addition to the inquiry knowledge, the professional development must also incorporate teacher's core teaching conceptions (Lotter, Harwood, & Bonner, 2007). The SOLO taxonomy, the **S**tructure of the **O**bserved **L**earning **O**utcome (Biggs & Collis, 1982), is a model of learning that helps develop a common understanding and the language of learning, helping teachers to understand the learning process.

By analyzing the practical work by using the SOLO taxonomy reveals whether or not the activities carried out in the laboratory support only superficial learning and do not encourage learners to proceed towards deeper learning by providing opportunities for development of higher order thinking skills. Higher order thinking skills comprise for example problem solving, decision making, question asking and critical thinking skills (Zoller & Nahum, 2012). Laboratory activities should match the developmental level of the learners and even encourage them to move towards more sophisticated laboratory experiments of which they do not have experiences yet. With experience, learners gain greater confidence in dealing rationally with empirical problems. According to Paavola, Lipponen and Hakkarainen (2004) it is important that in schools learners engage themselves in knowledge-creating inquiry in order to develop an identity, where they can consider themselves both as consumers and creators of knowledge. Learning is known to be efficient when practical work is designed to encourage the interplay between observation and ideas during practical activity (Abrahams & Millar, 2008).

Inquiry is an active learning process in which students answer research questions through data analysis (for example Bell, Smetana, & Binns, 2005). Most students need scaffolding to develop scientific questions and to design data collection procedures to answer research questions. Teachers are not in general enthusiastic about practical chemistry at upper secondary level because, according to them, it takes too much time and practical chemistry plays only a minor part in the matriculation examination (Tomperi, 2015). Laboratory activities can be designed at varying levels of inquiry depending on e.g. the resources available and students' skills. It is important that a teacher recognizes the level of inquiry and provides students with tasks that are in line with the learning goals. The degree of inquiry depends on who is responsible for the activity as presented in Table 1 (Schwab, 1962; Abrams, Southerland, & Evans, 2007).

Table 1. Levels of inquiry (Schwab, 1962; Abrams et al., 2007)

Levels of inquiry	**Research question**	**Data collection method**	**Interpretation of results**
0: Verification	Given by teacher	Given by teacher	Given by teacher
1: Structured	Given by teacher	Given by teacher	Open to student
2: Guided	Given by teacher	Open to student	Open to student
3: Open	Open to student	Open to student	Open to student

How can we combine levels of inquiry with SOLO levels? SOLO taxonomy provides a simple and powerful way of describing how learning outcomes grow in complexity illustrating a continuum from surface to deep learning. It is based on the Piaget's sequence of cognitive development reflecting the understanding of science at five hierarchical levels, where each level builds on the skills that were acquired at a previous one (Biggs & Collis, 1982). Each level moves on to the next in order. The highest SOLO level, extended abstract, includes all four lower SOLO levels. Inner squares in Figure 1 illustrate research questions linked with water at different SOLO levels.

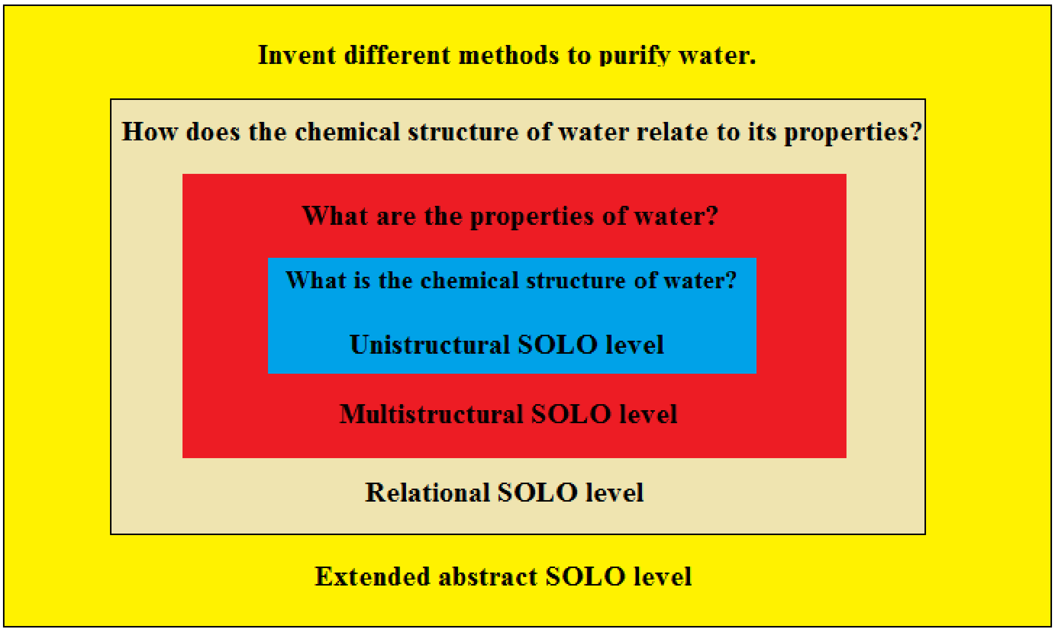

Figure 1. The complexity of questions increases when moving between SOLO levels in order. The highest SOLO level (yellow), extended abstract, includes other SOLO levels.

The first three levels of SOLO taxonomy are quantitative in nature because the amount of information increases. Instructions at these levels usually represent verification laboratory where learners are mainly asked to follow detailed instructions to obtain predetermined results, or to verify a concept that is already familiar to learners. Typically, if students are asked to interpret the results, laboratory work at unistructural and multistructural SOLO levels represent the first level inquiry task (see Table 1). (Tomperi & Aksela, 2009) These types of instructions are needed when learners do not have any previous knowledge about the topic (prestructural) or they know one fact (unistructural) or many facts (multistructural) about the topic but without coherence or interrelated aspects.

The fourth level of SOLO taxonomy is called relational and it is qualitative in nature because the relations between facts start to emerge forming a structure. It corresponds either to the structured level of inquiry, where learners investigate a given research question by using a prescribed procedure, or guided level of inquiry, where learners investigate a teacher-presented question by choosing the research method and interpreting results (see Table 1). Students are guided and supported to draw a general conclusion from the available data by induction.

The highest level of the SOLO taxonomy, the extended abstract, corresponds to the open inquiry in which students investigate topic-related questions that are student formulated through student selected/designed procedures. The open inquiry is the most demanding way for students to work and, according to teachers, it would be feasible only at the specific laboratory course as a science project (Tomperi, 2015). At the extended abstract level, learners additionally generalize the abstract principle to another context outside their own experience by deduction. At the relational level, the information needed is usually found in a chemistry book or in the material provided during the course, whereas at the extended abstract level more information is needed from outside sources (Biggs & Collis, 1982; Biggs & Tang, 2007).

Using SOLO taxonomy to design particular intended learning outcome instructions is helped by using verbs from Table 2 that parallel taxonomy. Some verbs can belong to different SOLO levels depending on the context in which the verb is deployed, for example, the verb ‘paraphrase’ is multistructural, when students replace like-meaning phrases, and relational, when the meaning of the whole text is rethought and then rewritten (Biggs & Tang, 2007).

Table 2. Some useful verbs from the SOLO taxonomy according to Biggs & Tang (2007)

SOLO level	Examples of verbs
Unistructural	Memorize, recognize, count, define, identify, name, draw, find, label, match, quote, recall, recite, order, tell, write, imitate
Multistructural	Describe, list, classify, report, discuss, illustrate, select, outline, compute, narrate, sequence, separate, paraphrase
Relational	Apply, analyze, compare, contrast, explain, conclude, summarize, review, argue, transfer, make a plan, solve a problem, organize, relate, debate, construct, predict, argue
Extended abstract	Generate, reflect, hypothesize, theorize, generalize, prove from first principals, compose, create, invent, originate, solve from first principals

To promote inquiry in classrooms, SOLO taxonomy was introduced to the chemistry teachers as a tool to evaluate the quality of assignments which teachers pick up for practical work. Research-based STEM training of chemistry teachers aimed at expanding a teacher's role as a dispenser of knowledge to a researcher of one's own work and a learner (Tomperi & Aksela, 2014). Teachers can modify existing instructions into a problem solving task with the help of SOLO taxonomy to match the learning goals and to build opportunities for students to develop higher order thinking skills. The development of learning material and interaction-based sharing of ideas together with enactment of created material in classroom leads to the development of the teachers' pedagogical content knowledge (PCK) according to interview after training, which is consistent with recent research by Coenders and Terlouw (2015).

Information about teachers' professional development using SOLO taxonomy was obtained in the design process of an eight-phase design research project (Edelson, 2002) which employed qualitative research methods of observation, survey and interview. Data was analyzed using content analysis. According to research results, teachers need training of various durations. If a teacher's view on student learning is congruous with inquiry, they may start practicing the implementation of inquiry during short training. SOLO taxonomy supported teachers' professional development in many ways: for example, it worked as a tool in designing and modifying written instructions, motivated teachers to develop their practices, increased teachers' ownership to created material, supported teachers' understanding of inquiry and acted as a model for higher-order thinking skills (Tomperi, 2015).

The SOLO taxonomy does not tell us how to teach. In a constructivist model of learning, teachers function as helpers and resources answering students' questions with a question and referring them to find information from different sources and from peers (Blanchard et al., 2010). It is well known that chemistry books play a central role in focusing on a student's behavior and learning. We investigated the laboratory tasks in all the available course books for the obligatory chemistry course in Finland and found out that the majority of tasks were of verification type and quantitative chemistry (Tomperi & Aksela, 2009). Students usually work in small groups, and good instructions support collaborative group work. Otherwise, if students can divide the experiment in the group into separate tasks and each member of the group pursues the sequence of tasks by themselves, there is a risk that they cannot form a general view of the problem under investigation.

According to a constructivist model of learning, knowledge is constructed by an individual through active thinking, and social interaction is necessary in creating a shared meaning. Laboratory work should not be the goal in itself but the learning experience which provides means to a learner's mental activity (Bybee, 2006).

Päivi Tomperi
Lic. Phil. (physical chemistry; subject teacher in chemistry and mathematics)
Ph.D. (research in chemistry teaching)
phtomper@gmail.com

Specialization: Expert in practical chemistry, inquiry, research-based professional development and supporting teacher learning by using SOLO taxonomy. Defended her doctoral dissertation in The Unit of Chemistry Teacher Education in 2015. The subject of the doctoral dissertation was research-based development of STEM training.

References

Abrahams, I. & Millar, R. (2008). Does Practical Work Really Work? A Study of the Effectiveness of Practical Work as a Teaching and Learning Method in School Science. *International Journal of Science Education*, 30(14), 1945-1969.

Abrams, E., Southerland, S. A. & Evans, C. (2007). Inquiry in the classroom: Identifying necessary components of a useful definition. In E. Abrams, S. Southerland, & P. Silva (Eds), *Inquiry in the science classroom: Challenges and Opportunities.* Charlotte, North Carolina: Information age publishing, 11-42.

Bell, R.L., Smetana, L., & Binns., I. (2005). Simplifying inquiry instruction. Assessing the inquiry level of classroom activities. *The Science Teacher*, 72(7), 30-33.

Biggs, J. B. & Collis, K. F. (1982) *Evaluating the quality of learning: the SOLO taxonomy*. Academic Press: New York.

Biggs, J. B., & Tang, C. (2007). Teaching for quality learning at university: What the student does. Maidenhead: McCraw-Hill/*Society for research into higher education*, 3rd Edit.

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, W. D., Annetta, L. A., & Granger, E. M. (2010). Is inquiry possible in light of accountability? : A Quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Education*, 94, 577-616.

Bybee, R. W. (2006). Scientific Inquiry and Scientific teaching. In L. B. Flick, & N. G. Lederman (Eds) *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education*. Dordrecht: Springer, 1-14.

Coenders, F., & Terlouw, C. (2015). A model for in-service teacher learning in the context of an innovation. *Journal of Science Teacher Education*, 26(5), 451-470.

Edelson, D. C. (2002). Design research: What we learn when we engage in design? *The Journal of the Learning Sciences*, 11, 105-121.

Lotter, C., Harwood, W. S., & Bonner, J. J. (2007). The influence of core teaching conceptions on teachers' use of inquiry teaching practices. *Journal of Research in Science Teaching*, 44(9), 1318-1347.

Paavola, S., Lipponen, L., & Hakkarainen, K. (2004). Models of innovative knowledge communities and three metaphors for learning. Review of *Educational Research*, 74(4), 557-576.

Schwab, J. J. (1962). The teaching of science as enquiry. In J. J. Schwab, & P. F. Brandwein (Eds) *The teaching of science*. Cambridge, MA: Harvard University Press, 1-103.

Tomperi, P. (2015). *Kehittämistutkimus: Opettajan ammatillisen kehittymisen tutkimusperustainen tukeminen käyttäen SOLO-taksonomiaa – esimerkkinä tutkimuksellinen kokeellinen kemian opetus (Design research project on inquiry-based practical chemistry instruction: Supporting teachers' research-based professional development using SOLO-taxonomy)* (Doctoral dissertation). Retrieved from: https://helda.helsinki.fi/handle/10138/158059

Tomperi, P. & Aksela, M. (2014). In-service teacher training project on inquiry-based practical chemistry. *LUMAT*, 2(2), 215-226.

Tomperi, P. & Aksela, M. (2012). *Promoting inquiry-based practical chemistry using SOLO taxonomy*, Proceedings ICCE - ECRICE, CnS-La Chimica nella Scuola, XXXIV-3, 388-392.

Tomperi, P. & Aksela, M. (2011). Opettajien kokeellisten laboratoriotöiden valinnat (Chemistry teachers' choices for a laboratory assignment). In M. Aksela, J. Pernaa, & M. Happonen (Eds) *Kansainvälinen kemian vuosi: Kemia osaksi hyvää elämää* (s. 84-95). VI Valtakunnalliset kemian opetuksen päivät. Retrieved from: http://www.helsinki.fi/kemma/data/kop-2011.pdf

Tomperi, P. & Aksela, M. (2009). Lukion kemian pakollisen kurssin oppikirjojen laboratoriotöiden analysointi käyttäen SOLO-taksonomiaa (Analysis of laboratory assignments in the chemistry books of the obligatory chemistry course using SOLO taxonomy). In M. Aksela & J. Pernaa (Eds) *Arkipäivän kemia, kokeellisuus ja työturvallisuus kemian opetuksessa perusopetuksesta korkeakouluihin* (s. 152-159). IV Valtakunnalliset kemian opetuksen päivät. Retrieved from: http://www.helsinki.fi/kemma/data/kop-2009.pdf

Tomperi, P. & Aksela, M. (2008). Tutkimuksellinen kemian kokeellinen oppiminen lukiossa (Inquiry-based practical chemistry learning at upper secondary level). In J. Välisaari & J. Lundell (Eds) *Kemian opetuksen päivät 2008: Uusia oppimisympäristöjä ja ongelmakeskeistä oppimista* (s.113-118). Jyväskylän yliopiston kemian laitoksen tutkimusraportti No.129. Retrieved from: https://www.jyu.fi/kemia/tutkimus/opettajankoulutus/kop2008/artikkeli_15

Tuomi, L., & Sarajärvi, A. (2009). *Laadullinen tutkimus ja sisällönanalyysi* (Qualitative research and content analysis). 5. painos. Helsinki:Tammi.

Zoller, U., & Nahum, T. L. (2012). From teaching to KNOW to learning to THINK in science education. In B.J. Fraser, K. G. Tobin, & C. J. McRobbie (Eds) *Second International Handbook of Science Education*. Dordrecht: Springer Netherlands, 189-207.