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Making the learning of chemistry more relevant for students

Fer l'aprenentatge de la química més rellevant per als estudiants

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abstract

Science teachers have to make the learning of science more relevant to their students. This is an often-heard claim when it comes to reforms in science education in general and in chemistry education in particular. However, it is not always clear what is meant by «making the learning of science more relevant». This paper reflects some theoretical and practical works about the meaning of relevance in science education and about potential teaching strategies to make science education more relevant to students in terms of individual, societal and vocational relevance, as well as to raise students' perception thereof.

keywords

Scientific literacy, relevance, context-based learning, socio-scientific issues, doping, tattooing.

resum

Els professors de ciències han de fer que l'aprenentatge de la ciència sigui més rellevant per als seus estudiants. Aquesta és una demanda freqüent quan es tracta de reformes en educació científica, en general, i en educació en química, en particular. No obstant això, no sempre és clar el que significa «fer que l'aprenentatge de la ciència sigui més rellevant». Aquest treball reflecteix alguns treballs teòrics i pràctics sobre el significat de la rellevància en l'educació científica i sobre les possibles estratègies d'ensenyament per fer que l'educació científica sigui més rellevant per a l'alumnat en termes de rellevància individual, social i professional, així com augmentar la percepció dels estudiants.

paraules clau

Alfabetització científica, rellevància, aprenentatge basat en el context, controvèrsies sociocientífiques, dopatge, tatuatge.

«Doping» for chemistry education

Context-based science education seeks to contextualize science content by topics from life, society or technology to make science learning a more meaningful experience for the learner (Eilks, Rauch, Ralle & Hofstein, 2013). However, not every context chosen by curriculum developers or teachers might be considered to be meaningful or even interesting by the students. Often, contexts are selected from a teachers' perspective, instead of a student's one. Socio-scientific issues-based approaches to the curriculum move further. They suggest to embed the learning of science into contexts of a specific type. SSI approaches use contexts that are relevant for society in general and to students as being part of it in particular. Marks & Eilks (2009) suggested understanding *relevant* in this respect to whether there is a question where there is an open situation and a decision is needed to be made.

Let us allow to illustrate this with a simple example. Modern analytical chemistry is able to detect even very small portions of certain substances. This technology is used at airports to detect explosives in the luggage. The technology can be used to contextualize (and maybe motivate) learning of analytical chemistry. However, this context is not containing any open questions whether to apply this technology or whether it might cause any risks both to the individual and to society. Marks & Eilks (2009) suggested criteria for challenging socio-scientific contexts to be used in science classes, namely authenticity, relevance, openness in a societal debate, discussible and its relation to science. This framework questions whether there is any motivation to debate about the use of this technology.

It can meaningfully contextualize chemistry learning. However, it does not challenge any decisions where the knowledge from chemistry might help, neither for the individual nor for society. With the suggestion of Stolz, Witteck, Marks & Eilks (2013), it is neither even sufficiently authentic, nor relevant since there is no debate about this technology present in the public media, nor is there any decision to come whether to use this technology or not. It will be used and is of benefit to everyone.

A different story is the story of doping in sports (Stolz *et al.*, 2013). This topic is highly present in the public media. There are continuously decisions to come whether to restrict certain new substances or techniques, whether to enforce stronger controls, whether to implement stronger punishments (or whether to give it for free). There are different opinions available in the public showing the openness of the issue. Some people want stronger controls, others suggest lowering the punishments. You can follow one position or another if it comes to the use of food supplements, drugs or illegal doping substances in leisure sports or the fitness arena. And, of course, doping is an issue of science in general and chemistry in particular. In fact, doping is a race between the drug designer (maybe a bio-chemist) and the investigator (most probably an analytical chemist).

In 2013, we suggested that doping has a lot of different aspects that might be considered by students to be relevant for them, society or potential workplaces (Stolz *et al.*, 2013):

— Many students are TV-consumers of professional sports.

— Doping is a question in professional sports, but also in the fitness arena and in leisure sports.

— Unconscious doping by drugs can happen to everyone.

— The line between food supplements, drugs and illegal doping is often not clear.

— Doping in professional sports is controversial: some favor stronger punishments, others suggest giving it free.

— Who do decide to whether a certain substance should be considered illegal doping?

— Sports funding and sports industries depend on the prospects of modern doping analytics.

— Biochemistry, medicine, analytics, but also fitness, sports and media offer rich chances for finding a good job in future.

As a case, we developed a lesson plan on learning about essentials of analytical chemistry embedded into the socio-scientific issue of doping (table 1) (Stolz *et al.*, 2013) based in the curriculum model suggested by Marks & Eilks (2009) (fig. 1).

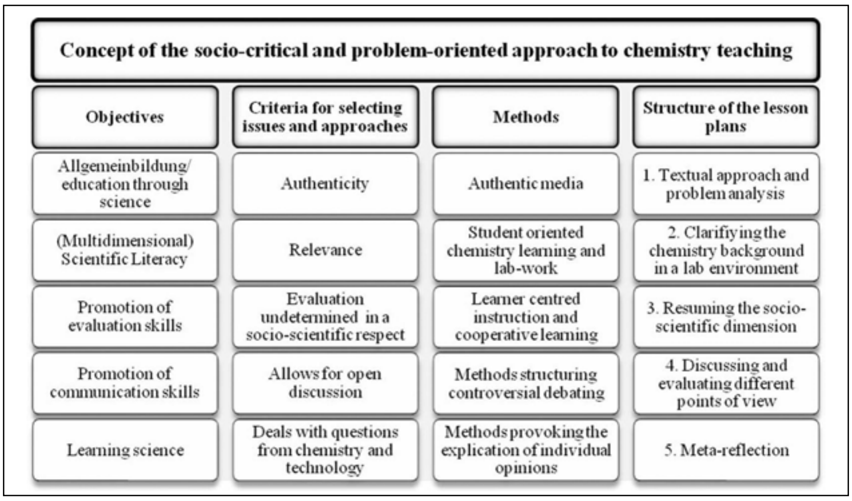


Figure 1. The model of a socio-critical and problem-oriented approach to chemistry or science education (Marks & Eilks, 2009).

Table 1. A lesson plan on analytical chemistry (grade 10/11) embedded into the issue of doping

Step	*Activity*	*Focus*
Textual approach and problem analysis.	Analyzing excerpts from authentic newspaper articles.	Doping in professional sports and health problems caused by misuse of doping substances in the fitness arena.
Clarifying the chemistry background in a lab environment.	Learning at stations with experiments and theoretical inputs.	Selected analytical techniques, *e.g.* chromatographic and spectroscopic methods.
Resuming the socio-scientific dimension.	Jigsaw classroom.	Differentiating legal food supplements, drugs and illegal doping substances use along different examples.
Discussing and evaluating different points of view.	Role play of a TV talk-show.	Controversial societal positions on doping in professional sports.
Meta-reflection.	Reflecting the role play.	How society does come to decisions.

The idea of the lesson plan was to raise the relevance of chemistry learning and students' perception thereof. The students reacted very positively to the lesson plan:

— Some considered the lesson plan to be interesting to them and their personal lifeworld.

— Some saw it as meaningful to see where understanding chemistry is good for.

— Some described a potential impact of doping on their lives.

— Some mentioned to have learned about handling scientific issues in the society they live in and operate.

— Some mentioned the medical dimension and the dimension of potential careers.

However, is this what we mean when we claim to make chemistry learning more relevant for students?

The meaning of *relevance* in the science curriculum

Relevance is one of the most often used terms when it comes to reforms in science education (Stuckey, Mamlok-Naaman, Hofstein & Eilks, 2013). However, in the past it was often used without explaining what was meant when teachers were urged to make their teaching of science in general, or chemistry in particular, more relevant. Already, in 1988, Douglas P. Newton, from the United Kingdom, wrote:

> The notion of *relevance* is not a simple one. It seems at the least unhelpful and at the worst counterproductive to urge a teacher to be relevant in terms which are abstract and diffuse. It might be useful if some aspects of the notion of *relevance* were to be clarified.

However, this was not done for almost twenty-five years. An analysis of the literature in science and general education from the last fifty years by Stuckey, Mamlock-Naaman, Hofstein & Eilks (2013) revealed that there are many different uses of the term *relevance* in science education, namely:

— More or less as a synonym for *interest* (Schreiner & Sjøberg, 2004; Matthews, 1994; Ramsden, 1998).

— As acknowledgement of meaningfulness (Schollum & Osborne, 1985; Westbroek, Klaassen, Bulte & Pilot, 2005).

— As a perception of worth for fulfillment of needs (Keller, 1983).

— As a prerequisite for coping with future needs (Levitt, 2001).

— As a base for economical wealth and development (Knamiller, 1984).

— As a base for decisions that impact life (Marks & Eilks, 2009).

— As under-defined but multidimensional construct (Rannikmäe, Teppo & Holbrook , 2010).

Already, Newton (1988) uncovered that there are different meanings, fields or dimensions of *relevance*:

> Science education is to place science in broader contexts of one form or another so that students see its wider significance in their own lives and in the lives of others. Where such contexts are provided, the practical utility of science often figures largely. [...] Relevant science teaching might support more than one such aim and each to differing degrees, according to how his own, the student's, society's and science's present and future needs are perceived.

Based on the literature, we recently analyzed the meaning of *relevance* (Stuckey, Mamlock-Naaman, Hofstein & Eilks, 2013). We suggested a definition and created a model about the understanding of *relevance* when it comes to science education. It is suggested that science learning becomes relevant education when the learning will have (positive) consequences for the student's life. Positive consequences can be: *a*) fulfilling actual needs laid down in the student's interest or educational demands (that students will perceive actually), as well as *b*) in the anticipation of future needs (that the students not necessarily might be aware of). Relevance of science education covers intrinsic and extrinsic components. The intrinsic dimensions encompass student's interests and motives; the extrinsic dimension cover ethically justified expectations of the personal environment or from within society towards the student.

We also found three different dimensions in which this definition manifests, namely:

— The individual dimension: *e.g.* science learning meeting students' curiosity and interest, developing skills for coping their everyday life today and in future, contributing the students' intellectual skill development…

— The societal dimension: *e.g.* understanding the interdependence and interaction of science and society, developing skills for societal participation, skills for contributing society's sustainable development…

— The vocational dimension: *e.g.* orientation for future professions, preparation for further academic or vocational training, keeping formal career chances open…

— All this led into a model of relevance of science education as it is given in fig. 2 with exemplary entries in each corner of the three

Many chemistry and science curricula all over the world are still too much oriented along the structure of the discipline and factual content learning

different layers, namely: individual, societal and vocational relevance. A validation study with experts from science education, from student teachers towards experienced teachers and science education researchers suggests that this is a comprehensive model for understanding and balancing the different dimensions of relevance in science education (Stuckey, Sperling, Mamlok-Naaman, Hofstein & Eilks, 2014). However, the study also revealed that the societal dimension is often the most neglected one when it comes to secondary science teaching (Stuckey, Sperling, Mamlok-Naaman, Hofstein & Eilks, 2014; Hofstein, Eilks & Bybee, 2011).

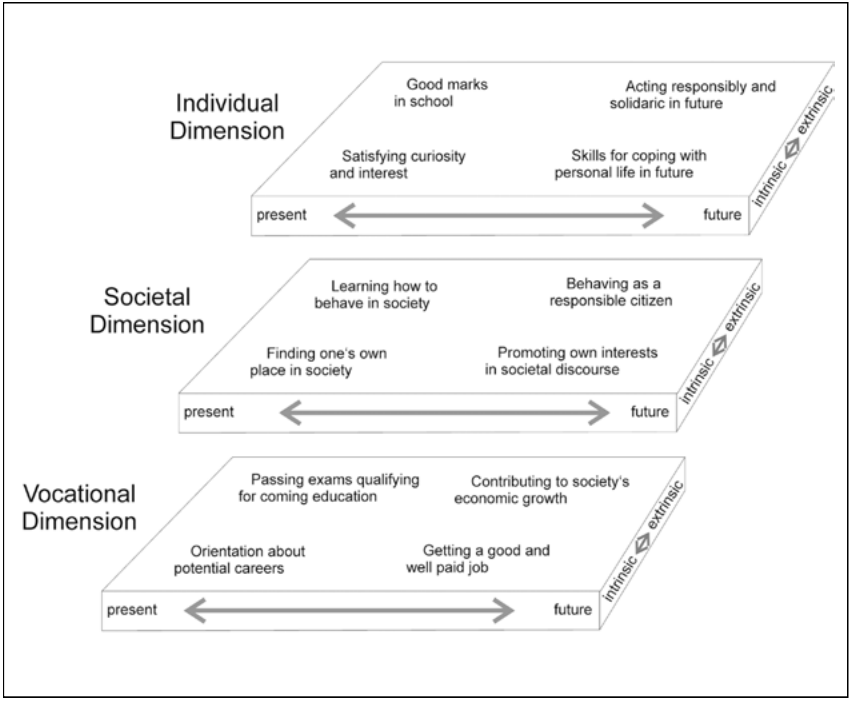


Figure 2. A model of understanding the meaning of relevance *when it comes to science education.*

Alternative views on the science curriculum

Many chemistry and science curricula all over the world are still too much oriented along the structure of the discipline and factual content learning (Eilks *et al.*, 2013). The societal dimension of chemistry education and understanding both the nature of science and how science is embedded into society are not well understood and neglected in the curriculum too often (Hofstein, Eilks & Bybee, 2011; Stuckey, Heering, Mamlok-Naaman, Hofstein & Eilks, 2015). If contexts are chosen, they are often chosen based on the content to be taught; many of them would not fit a reflection on the relevance of chemistry education as described above (Eilks, Ralle, Rauch & Hofstein, 2013). Also, one can see that career orientation, career preparation and the vocational aspects of relevant chemistry education are largely neglected in many chemistry teaching practices (Stuckey, Mamlok-Naaman, Hofstein & Eilks, 2013; Stuckey & Eilks, 2014).

The framework of relevant chemistry education described above (fig. 2) (Stuckey, Mamlok-Naaman, Hofstein & Eilks, 2013; Eilks & Hofstein, 2015) asks to re-orient the basic orientation and emphasis of the chemistry curriculum. A model by Marks & Eilks (2009), used above, explicitly refers to educational theories that might help in this re-orientation, namely *Allgemeinbildung*, education through science based on activity theory and multidimensional scientific literacy. All these three humanistic theories ask for a stronger societal orientation of school science and chemistry curricula. They ask for understanding science education as part of forming the responsible citizen of tomorrow, instead of only focusing the preparation of future scientists and engineers.

The three theories developed over a very long time (Hofstein, Eilks & Bybee, 2011; Sjöström & Eilks, 2017). However, many science and chemistry education practices at the secondary level are still neglecting them. There is a need to re-think the theory of the science curriculum based on basic educational theories to overcome the structure-of-the-discipline approach in science and chemistry teaching that was dominant in science curricula in Western countries until the 1970 (Eilks, Ralle, Rauch & Hofstein, 2013) and still is in many countries all over the world (*e.g.* Khaddour, Al-Amoush & Eilks, 2017). Maybe it is even time to overcome the context-based approach towards critical curricula that are driven by authentic and controversial socio-scientific issues, as the doping example described above. This might take the view of educating the individuals to allow them to transform their lives, society and the world in a responsible and eco-reflexive way for a better future (Sjöström, Eilks & Zuin, 2016; Sjöström & Eilks, 2017) (fig. 3).

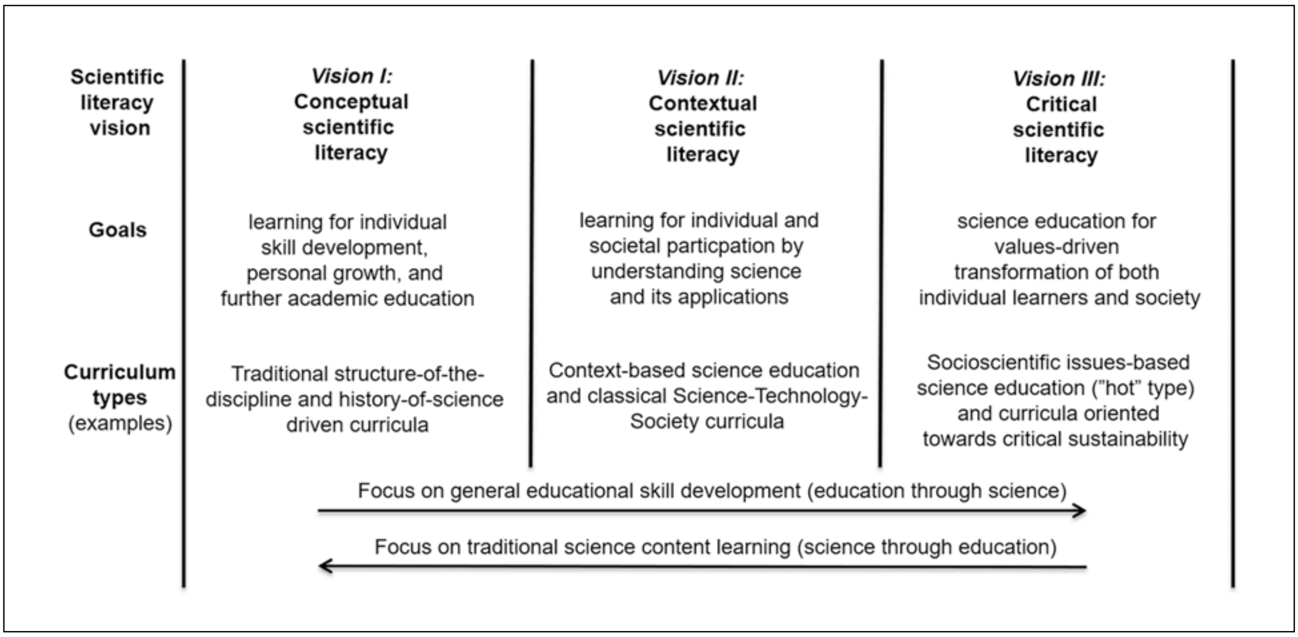


Figure 3. An extended view on visions of scientific literacy (Sjöström, Belova, Zuin & Eilks, 2017).

Such an approach will have to focus on a more intense learning about the nature of science today, about the interaction of science with society and about the influence on and use of science by society, its stakeholders and individuals. We will need a focus on topics that are relevant in all the three relevance domains. Corresponding curricula need to include societal and vocational aspects more thoroughly and thus embed cross-curricular goals necessary for a self-determined and responsible life in society (Belova, Dittmar, Hansson, Hofstein, Nielsen, Sjöström & Eilks, 2017). Such cross-curricular goals encompass understanding society's handling of techno-scientific issues, learning for societal participation and transformation, critical scientific media literacy beyond the news media, life and action for sustainability, career orientation (also beyond traditional science-related professions), employability skills and innovation competence (Belova, Dittmar, Hansson, Hofstein, Nielsen, Sjöström & Eilks, 2017). Finding corresponding topics and activities might start by reflecting on the model described in fig. 2.

Tattooing: operating the theory into feasible chemistry classroom practice

Taking the theoretical framework described above into account, some years ago we started searching issues that meet all the criteria and visions mentioned above. One example that we found was the issue of tattooing. Tattoos are currently popular and it is noticeable that younger people frequently have colored tattoos injected under their skin. *E.g.* in the United States more than 20 % of the citizens have had their skin tattooed. All in all, in the Western world, already in 2008, more than 100 million people had tattoos (Stuckey & Eilks, 2014). Tattooing meets the three different dimensions of relevant science education from individual, via societal, towards vocational relevance for the student:

— There is authentic debate and consulting on tattooing in youth related media.

— Many sports and pop stars have tattoos; these are idols and role models for the youth.

— A tattoo can harm the skin and cause allergies if it is not properly done.

— Germany has a restrictive law on tattooing that is under debate whether restrictions shall be lowered for children below 18, or even below 16.

— Germany's policy agreed on a certification system for tattoo inks and materials that does not exist in other countries or on the European level.

— If there are problems with tattooing, shall the therapy being paid by the public health insurance system?

— One can buy uncertified tattoo inks via the Internet, so there might be need for more control.

— Tattoos done in young age can hinder future careers in banks or insurance companies

Such an approach will have to focus on a more intense learning about the nature of science today, the interaction of science with society and about the influence on

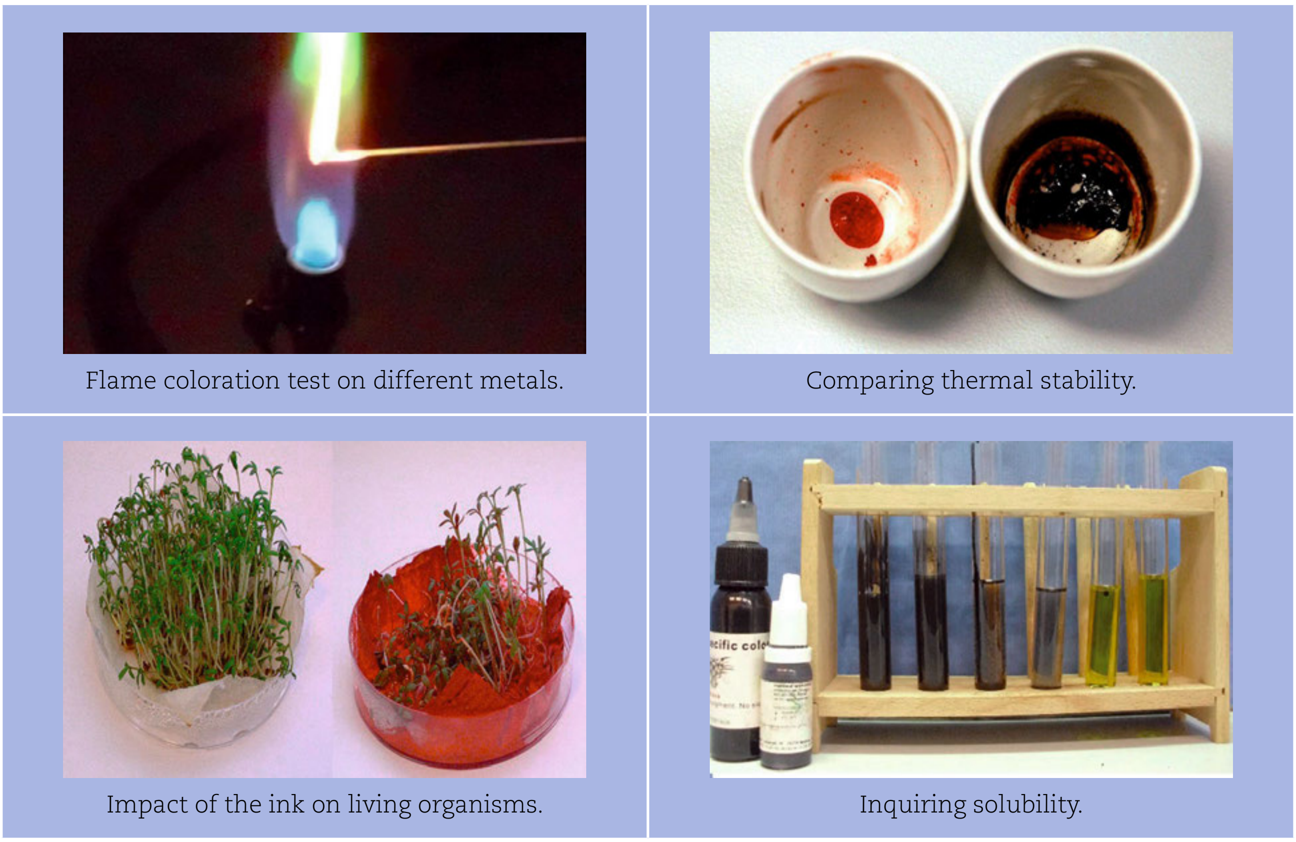
— Knowledge about tattooing chemistry is necessary in many jobs: tattoo artists, doctors, tattoo removers, psychological and medical consultants.

So we developed a lesson plan on tattooing (table 2) (Stuckey & Eilks, 2014), operating the same framework described above (Marks & Eilks, 2009) and using a whole set of newly developed experiments (fig. 4) (Stuckey & Eilks, 2015*a*; Stuckey & Eilks, 2015*b*).

Also this lesson plan was very well perceived by the students (Stuckey & Eilks, 2014; Stuckey & Eilks, 2015*b*). They (grade 9, 14-15 years old) really felt the relevance of the issue to their life and future

Table 2. A lesson plan on analytical chemistry (grade 10/11) embedded into the issue of doping (Stolz, Witteck, Marks & Eilks, 2013) based on the curriculum model by Marks & Eilks (2009)

Step	*Activity*	*Focus*
Textual approach and problem analysis.	Analyzing a fictive self-test from a youth magazine (inspired by an authentic one from the Internet).	Different aspects relevant to decisions about getting a tattoo: medical, aesthetic, societal and vocational aspects.
Clarifying the chemistry background in a lab environment.	Learning at stations with experiments and theoretical input.	Properties of certified and uncertified tattoo inks in comparison.
Resuming the socio-scientific dimension.	Teacher impulse.	Under which conditions tattooing is safe and shall be allowed.
Discussing and evaluating different points of view.	Answering a letter to a consultancy section of a youth magazine.	Aspects available to consult young people on tattooing.
Meta-reflection.	Reflecting the answering process.	Who answers to requests in consultancy sections in the media (and under which criteria)?



Flame coloration test on different metals.

Comparing thermal stability.

Impact of the ink on living organisms.

Inquiring solubility.

Figure 4. Some selected experiments with certified and uncertified tattoo inks (Stuckey & Eilks, 2015a, 2015b).

Also this lesson plan was very well perceived by the students (Stuckey & Eilks, 2014; Stuckey & Eilks, 2015*b*). They (grade 9, 14-15 years old) really felt the relevance of the issue to their life and future. Although the lesson plan was just a few hours long, a statistical significant raise in motivation was observed, based on the change in the curriculum and not in the pedagogy (Stuckey & Eilks, 2014). Exemplary quotes from the qualitative feedback support and illustrate this finding:

> The most important issue was to learn that there can be toxic substances in tattoo colors. And that you should better think three times whether to get a tattoo.
>
> Later, I would like to have a tattoo. Now I know that I will ask the tattooist which kind of colors he is using.
>
> I liked the lesson plan for the last hours. I enjoyed to learn so many different things about tattooing.
>
> The lesson plan was great, because I learned many different things and the topic was very interesting.
>
> I enjoyed the teaching unit because we made a lot of experiments and made many investigations.
>
> I enjoyed the experiments because I could better understand the content.
>
> I consider the teaching to be relevant because we dealt with an issue that interests many young people.
>
> The lesson plan was important for us [students] because many teenagers want to get a tattoo without thinking about the consequences.
>
> This lesson plan was relevant because one will reflect a second time to get a tattoo or not.

Final remarks

Feedback from students and teachers on both case studies show that the frameworks presented above are suitable to provide a road to more relevant and thus motivating chemistry and science education teaching practices. Teachers should feel encouraged to leave traditional content-based approaches and overcoming only to use contexts with low relevance to the students' life and future. There are other topics. These broadly relevant topics can lead to more motivated science learning, but also can contribute to critical scientific literacy oriented science education.

> Teachers should feel encouraged to leave traditional content-based approaches and overcoming only to use contexts with low relevance to the students' life and future. There are other broadly rellevants topics, which can contribute to the scientific literacy

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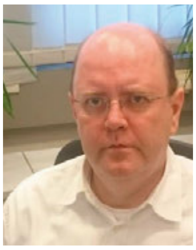

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