JOURNAL OF CHEMICAL EDUCATION

Laboratory Experiment

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Chemistry under Your Skin? Experiments with Tattoo Inks for Secondary School Chemistry Students

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Supporting Information

ABSTRACT: This paper discusses a set of easy, hands-on experiments that inquire into and differentiate among tattoo inks of varying quality. A classroom scenario is described for integrating these experiments into secondary school chemistry classes. Initial experiences from the classroom are also presented.

KEYWORDS: *Elementary/Middle School Science, High School/Introductory Chemistry, Dyes/Pigments, Hands-On Learning/Manipulatives, Inquiry-Based/Discovery Learning, Curriculum, Consumer Chemistry*

INTRODUCTION

Getting a tattoo is a very popular practice among many young people in modern Western societies. Popular musicians, sport stars and other celebrities wear tattoos and act as role models for younger generations. In Germany, slightly over one person in five in the 14- to 24-year-old age group has a tattoo.[1] Tattooing is also quite popular in the U.S., where more than 20% of the total population wears such body art.[2,3] Estimates for the Western world predict that over 100 million people have let themselves be tattooed.[4]

But tattoos can also be associated with health risks. Such risks generally are linked to infections stemming from insufficiently sterile tattooing procedures and questionable tattooing products found on the market.[5,6] Tattoo inks themselves also might present customers with the risk of bodily harm, e.g., cancer[7] or allergies.[8] The reason is that skin dyes contain a wide variety of different chemical compounds of which some might cause risk to the body, such as azo dyes, heavy metal compounds, or polycyclic aromatic hydrocarbons.[9] The most common metals used in pigments for tattoo inks are titanium or aluminum,[10] but also antimony, arsenic, beryllium, chromium, cobalt, lead, nickel, and selenium has been found.[7] A study in 2009 gave evidence that in many tattoo inks the concentration of chromium, nickel and cobalt exceeds safe allergological limits.[11] Some of the substances currently employed in traditional inks have proven to be toxic to the human body due to the presence of the heavy metal ions.[9] Others have fallen under suspicion that they may cause allergic reactions.[12] Degradation of some products through laser irradiation may also lead to toxic effects.[12−14] It was also found that the "natural alternative" henna in some cases could cause allergies too.[15,16]

The risks associated with tattoo ink under the skin depend on the process of proper tattooing as well as to both the type and quality of the dyestuffs used. Some countries, like Germany, have recently introduced stricter rules for tattooing. The rules limit the range of acceptable chemical compounds which can be used in tattoo inks, regulate declaratory guidelines for comprehensively labeling, and implemented a certification processes for tattoo inks. Such special regulation only for tattoo inks is currently not the case in the U.S.A.[6,17] However, even countries with strict tattooing regulations face wide-ranging difficulties since global trade makes it easy for people to order cheaper, quite possibly less-regulated alternatives from abroad via the Internet. These cheaper inks might be of lesser quality and safety, at least they are generally not labeled according to comprehensive declaratory rules, so that no proof is provided that they are nonpoisonous and nonallergenic.

This paper presents some easy classroom experiments for the junior high school level, which can be used to compare different sorts of tattoo inks. Learning about tattoo inks can be used to contextualize the chemistry of pigments and dyes. It also can be used to reflect upon the importance of chemistry in students' personal lives and decision-making processes.

Learners can inquire into which kinds of dyestuffs are used to manufacture a certain color of tattoo ink. If the ink bottle has

Published: October 14, 2014

been sufficiently labeled, the color index (CI) will show which compounds have been used. In many cases, the labels on cheap tattoo inks do not show the CI for the dyestuff in question. In such cases, pupils can be incited to develop their own simple analytical experiments, e.g., by comparing the unknown tattoo ink with colors for which they know the composition. Further investigations can also inquire into the stability of different inks or the particle size of the color pigments. In addition to inquiry into compounds and their properties, other experiments exist which investigate indications for the potential health risks of different tattoo inks. For example, students can also test whether a tattoo ink demonstrates toxicity to plants or inhibits enzymes.

■ EXPERIMENTS FOR INVESTIGATING TATTOO INKS

The experiments discussed here allow for student investigation of the toxicity, stability and other properties of tattoo inks. Different brands of tattoo ink can be compared and contrasted. For our study, we chose two different brands of tattoo ink. The first (Sailor Jerry; cost roughly $8 per 10 mL) is produced under strict German laws regulating allowable color composition (ordered from Amazon or Planet Clean[17]). These regulations also give precise labeling instructions for ink containers. The second, much cheaper alternative was ordered from an online warehouse in South-East Asia via the Internet (Tattoo Specific Color; ca. $1.50 per 10 mL; ordered from Ebay[18]). Beyond these two brands, students are free to evaluate any brands of tattoo ink which are available, including different colors of ink from one manufacturer, using either an inquiry-based or project-based approach in the classroom. For all the experiments, a detailed laboratory manual is available in the Supporting Information.

Detecting Metal Ions

One indication of whether metal ions are a component of tattoo inks can be provided by a flame-coloration test. A magnesia stick is dipped into hydrochloric acid and held in the flame of a Bunsen burner until the flame is colorless. A small drop of tattoo ink is placed on the top of the magnesia stick and held into the flame. If certain metals constitute part of the pigment, the flame will exhibit a specific color corresponding to particular metal atoms. As an example, blue tattoo inks regularly tend to yield a green flame due to the presence of copper atoms in the dyestuff.

In our case, the certified tattoo ink makes it clear from the color index that we are dealing with phthalocyanine blue (CI 74160) as a pigment. This compound is a copper complex (see Figure 1). On the labeled products, other metal ions can be identified by the CI in different inks. However, the cheap inks purchased on the Internet provide no labeling which clearly identifies the color compounds (Figure 2). This makes an identification of the chemical compound difficult. A comparison with the first ink yields an identical flame test, thus supporting the assumption that a copper compound has also been used. Further comparisons with pure metal salt solutions gives even stronger support. However, there is no easy, conclusive way to identify whether it is the exact same dye or whether another, similar copper compound has been substituted.

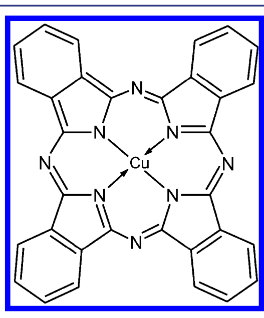

Figure 1. Phthalocyanine blue (CI 74160).

In more advanced chemistry classes at the senior high school or undergraduate level, further techniques borrowed from analytical chemistry can be introduced via this context. For example, we can test our blue tattoo ink with potassium ferrocyanide. Therefore, digestion with acid is necessary.[19] For each of the brands three drops of blue tattoo ink and 2 mL of concentrated nitric acid are placed in each a test tube under an exhaust hood. The mixture is carefully heated until only a dry residue remains. This residue is then dissolved in 5 mL of distilled water and boiled until it dries out again. The solid residue is further dissolved in another 5 mL of distilled water. A few drops of the resulting solution, which is colorless, are then added to a solution of potassium ferrocyanide.

$$\underset{\text{colorless}}{K_4[Fe(CN)_6]} + 2Cu^{2+} \rightarrow \underset{\text{red-brown}}{Cu_2[Fe(CN)_6]} + 4K^+$$

A color change to red-brown indicates that copper ions were present, which quickly react to form copper(II) ferrocyanide ($Cu_2[Fe(CN)_6]$).[20]

Thermal Stability

Thermal stability can also be easily tested. Two or three drops of red tattoo ink from different manufacturers (e.g., Sailor Jerry and Tattoo specific color) are each placed in separate porcelain containers. The beakers—closed with a porcelain lid—are then heated for 30 s using a Bunsen burner. In our experiments, we were able to show that there are several tattoo inks which are heat resistant. This suggests that these dyestuffs are composed by pigments which are stable even when strongly heated (e.g., irgazin red, CI 56220). Other colors of ink rapidly decompose and form a burned, muddy-brown mass. We can assume that such colors contain primarily organic dyes or nonheat resistant pigments. In our case, some of the cheap alternatives decomposed rapidly (see Figure 3). In general, for a tattoo which is supposed to last a lifetime it is, of course, advantageous to use stable pigments which avoid decomposition. There are already reports that some inks have been shown to lose their color when exposed to sunlight.[21]

Particle Size

The particle size of different tattoo inks can be investigated using a microscope. Inks can either be diluted or dispersed in a suitable solvent, which is then prepared on a microscope slide. Generally, particle sizes of the pigments vary from 10 to 5000 nm.[22] Different colors show varying particle sizes for the pigments and almost none of the inks can be completely dissolved. In our study, the average particle size for certified, regulated inks tended to be larger than that for cheap ones ordered in the Internet. Smaller pigment particle sizes mean higher risks that ink particles can cross through cell membranes and freely move throughout the body. Also this phenomenon has already been observed.[23,24]

Ink Solvents

The solvents used to make tattoo inks can also be investigated easily. A few drops of tattoo ink (e.g., of Tattoo specific color)

Figure 2. Certified inks (left) and insufficiently labeled alternatives (right).

Figure 3. (Left) Red tattoo ink from Sailor Jerry. (Right) Red ink from the company Tattoo specific color. Both after 30 s heating.

are placed in a porcelain dish, which is then covered with a watch glass. The dish is evenly heated until the solvent evaporates and condenses on the surface of the watch glass. Anhydrous copper sulfate is added to the condensation. The presence of water in the solvent will turn the pale, blue-white copper sulfate powder into vibrantly blue, hydrated copper sulfate, thereby demonstrating that the solvent used is water-based.

Solubility

Different tattoo inks can be placed in different liquids to test their solubility. The liquids employed can include water, ethanol or oil. If an ink dissolves in water, it can also dissolve or disperses easily if it comes into contact with blood. This can be problematic if the pigments are not put in the right skin layer (the corium). However, oil-soluble inks carry the risk that they might move into the fatty tissues of the body. This might not be so bad, since the pigments will remain in the fatty tissue, whereas blood-soluble inks may intrude into any part of the body.

Influences on Living Organisms

A simple experiment using enzymes might serve as an indicator of the potential influences which tattoo ink may exert on the human body.[25] A potato is carefully cut into pieces of the same size. These pieces are then exposed to different tattoo colors for about 10 min. All of the potato pieces are then placed into separate beakers filled with dilute hydrogen peroxide solution (3%).

Unaffected pieces of potato lead to a strong reaction, since the enzyme catalase catalyzes the decomposition of hydrogen peroxide into water and oxygen.[26]

$$2H_2O_2 \xrightarrow{\text{catalase}} 2H_2O + O_2$$

The reaction with most treated potato pieces is much less intense. This is because many of the metal ions found in tattoo inks, such as copper, inhibit catalase and therefore reduce enzymatic activity.

Garden cress provides a second example of the possible influence tattoo ink may have on living organisms. Samples of garden cress are watered with small amounts of dilute, aqueous solutions of various tattoo inks for 3–5 days. Several of the ink-solutions lead to reduced growth or even death among the garden cress plants.

Other Possibilities for Experiments Described in the Literature

At the university level this motivating context can be even used to introduce atomic absorption spectroscopy (AAS). With the help of AAS, proof can be provided that copper is part of the pigments in both the cheap and expensive inks. Students can use the AAS to determine the concentration of e.g. copper ions in the tattoo inks. This analysis helps the students learn about how to create standard plots and the value of standards in analytical chemistry. In another sense, students can apply more traditional qualitative chemical analysis in the form of select precipitation and/or complex formation reactions with different tattoo inks (e.g., with different metals). With regards to thermal stability of tattoo inks students might check whether thermogravimetric analysis (TGA) or differential scanning calorimetry (DSC) is able to better quantify the thermal stability of the tattoo inks. Maybe students can even try to identify the particle sizes. They could then apply statistics to such data (for both issues see the experiments below). Chamberlain and Rogers have even described an example of a science summer camp, which used tattoo inks to introduce the topic of ligand field theory.[27] They also described how students were able to make their own tattoos on pig feet, remove them with a laser beam, and learn about the dermatologic effects of tattoo removal.

■ HAZARDS

If the learners are inexperienced with respect to lab work, experiments should be done with small portions of tattoo inks and preprepared solutions or dispersions. These experiments use intense, concentrated dyes. Students should cover their work areas well and use gloves and safety goggles to protect themselves. Some experiments employ hazardous substances,

dx.doi.org/10.1021/ed400804s | J. Chem. Educ. 2015, 92, 129−134

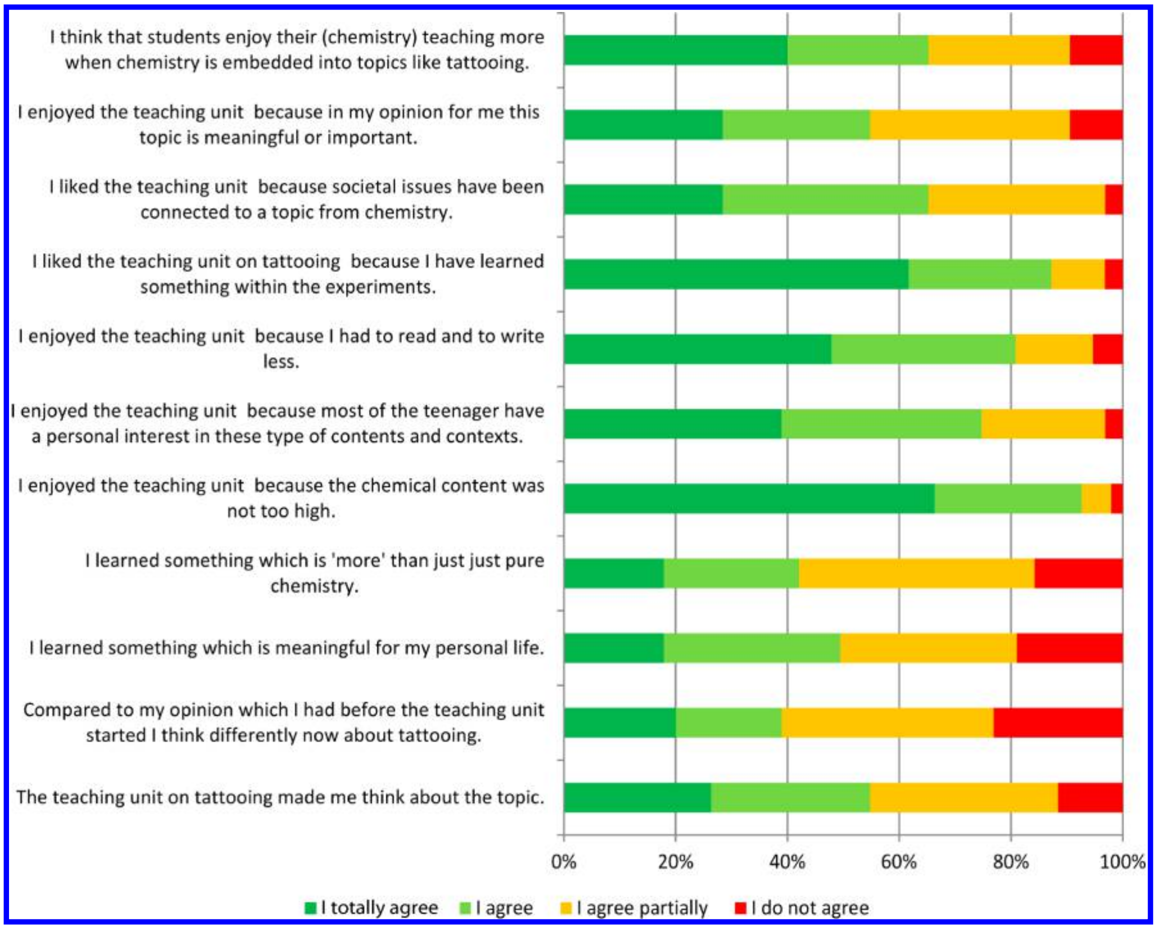

Figure 4. Results of the Likert-type feedback questionnaire.

for example, hydrogen peroxide solution. Therefore, safety regulations must be consciously taken seriously. At the high school level, the use of nitric acid should be handled by the teacher for that particular experiment. The use of gloves and table covers is recommended.

■ A CLASSROOM SCENARIO FOR LEARNING ABOUT TATTOO INKS AT THE SECONDARY SCHOOL LEVEL

Teachers can easily create learning environments where their students work on different inks via project-based learning or in a "learning-at-stations" lab. A project-based classroom allows the students to freely investigate the various inks and search for information on the Internet, so that they can produce posters or brochures addressing the risks of getting a tattoo. A "learning-at-stations" environment allows the teacher to introduce additional topics in a more systematic fashion.[28] Additional stations may include those dealing with tattoo ink regulations and labeling, the color index, the controversial reception of tattoos by the press, and tattoo removal techniques and/or risks when using laser-based ink-removal surgery.

To test the potential effects of the experiments, a lesson plan was designed by Participatory Action Research[29] based on the learning-at-stations pedagogy and operating an inquiry-based teaching and learning approach. Some stations were theoretical in nature and others focused on practical inquiries into different tattoo inks.[30]

Selection of the specific experiments and the guidelines given for carrying them out was attuned to a given learning group's practical skills and prior knowledge. All of the practical stations focused inquiring into and comparing two inks from two different manufacturers. More expensive inks produced under specific German regulations were compared to cheaper Internet products from South-East Asia. The students were asked to inquire into the difference between more expensive, quality inks and cheaper colors ordered in the Internet, including particle size, although even the more expensive ones under German law sometimes contain compounds that are under criticism concerning different healthy risks. Along with the example of copper, students had to learn about the different metal ions used in making the coloring compounds in tattoo ink and how to identify them. They also researched the potential interactions of tattoo ink with the living organisms.

A further set of stations focused on the health risks and allergenic potential of various dyestuffs from an informational perspective, as well as information on the techniques and risks of tattoo removal using laser beams. This information was provided in the form of texts, pictures and guided searches in the Internet. One of the informational stations focused on comparing the labeling of tattoo inks from the two different manufacturers. In this station, differences were to be found concerning the lack of content declaration on the cheaper product. Several misspellings found on the labels. Other informational stations addressed information about forthcoming German laws governing both tattoo inks and the tattooing procedure and procedures of tattoo removal.

Finally, the lesson plan was tested in five different learning groups with a total of 118 students at the junior high school level at a comprehensive school in Northern Germany (grade 9, age range 14−15). Feedback was collected by an open and a Likert-type questionnaire as well as from classroom observations. Additionally, a pre−post-test was conducted to see any effects of the lesson plan on student motivation.[30]

In all the learning groups the teacher reported that the pupils were astonished to hear that their chemistry lessons would examine tattoos, a topic stemming from their everyday world and areas of interest. Also after the lesson plan, student feedback in respect of the lesson plan revealed a highly feasible and motivating teaching module. The positive feedback from the classroom observations corresponds with the feedback recorded by the students, who generally enjoyed the teaching unit (Figure 4). The teaching unit also let the students think about tattoos more critically. More than half of the students agreed or agreed totally (another one-third partially agreed) that the lesson plan made them think more critically about tattooing. Students enjoyed the chemistry lessons working on the topic of tattooing. They liked the lesson plan because the topic is an important societal issue, close to their own personal life, and not just "pure" chemistry.

Most students intensely examined the chemistry of tattoo inks to be very relevant and became very motivated by this topic. The pre−post-test on motivation revealed a significant gain of motivation and perception of relevance due to the chosen issue of tattooing.[30] One student stated: *"I enjoyed the teaching unit because we performed lots of experiments and we could investigate all the inks."* Intense discussions took place about the science behind tattoos and the students' personal perceptions of getting a tattoo. Students also discussed the societal aspects of tattooing. They viewed this topic as relevant to their lives. Another student said: *"I think that this teaching unit was very useful, because many students will want to get a tattoo in a few years."* One school even invited a journalist. A follow-up report about the students' project was issued in a local newspaper.

■ CONCLUSIONS

The topic was perceived by both teachers and students to be highly motivating. Evaluation results of these lessons showed high student motivation suggesting that students see these lessons as highly relevant to their lives. As teenagers as young as 15 considering having a tattoo at such an early age, the students were thus very interested in these lessons, performing the experiments, and the reading pertinent material.

From the accompanying study, it is suggested that it is mainly due to the perception of relevance of the topic that made the teaching about tattooing in the junior high school level successful in terms of motivation. The results suggest that carefully selected contexts, which are chosen with a thorough view of individual, societal and vocational relevance of chemistry learning, might contribute to overcoming claims that state students are not interested or motivated to learn science.[30] Perhaps such an approach could contribute to combatting the frequent complaint of chemistry being unpopular and increasing the realization of how relevant the subject actually is.

■ LIMITATIONS

This study is a case study conducted in a specific learning environment in northern Germany. Students' perception of the lesson plan and their attitudes toward tattooing will be influenced by their cultural environment. If cultural norms significantly differ from typical Western world views, students' response to learning about tattoo colors might differ significantly.

■ ASSOCIATED CONTENT

Supporting Information

Notes for the instructors. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This work was done in the framework of the *PROFILES*-project. We gratefully acknowledge the funding from the European Union in the FP7-programme under grant agreement no. 266589.

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