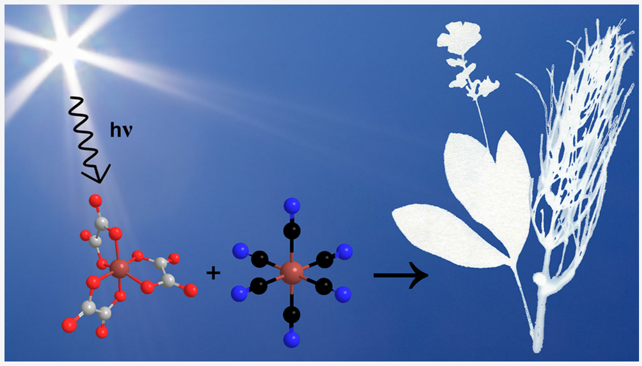
JOURNAL OF CHEMICAL EDUCATION
pubs.acs.org/jchemeduc Laboratory Experiment

The Cyanotype Process and Its Potential in Chemistry Education

Alexander Kmeť,* Anna Drozdíková, Soňa Nagyová, and Peter Ikhardt

Cite This: J. Chem. Educ. 2023, 100, 2367−2372 Read Online

ABSTRACT: Over the past few decades, the photographic process has slowly vanished from chemistry education in most schools. It happened due to vast changes in both technology and legislation. It is, however, helpful in demonstrating several concepts in natural sciences, bringing a bit of art into the subjects, and giving students an opportunity to express themselves while learning. The attractiveness of experiments may play a role in developing a positive attitude toward the subjects. Therefore, a photography-aimed laboratory experiment for elementary and high school education has been proposed. The cyanotype process was chosen due to its obvious advantages—it does not require extensive preparation or equipment and is easily administered even with elementary school pupils. A series of cyanotype workshops has been introduced in Slovak elementary and high schools with generally positive student response.



KEYWORDS: *Elementary School Science, High School Chemistry, Interdisciplinary/Multidisciplinary, Laboratory Instruction, Cyanotype, Photography, Coordination Compounds, Inorganic Chemistry*

■ INTRODUCTION

The word "photography" stands for both an art and a science of creating images by recording light. Thus, it is an interdisciplinary subject which lies between visual arts and natural sciences, namely chemistry and physics. There are very few interdisciplinary relationships between these two branches in an educational process, giving photography a special place. Photographic processes were conveniently used to demonstrate several concepts in various natural sciences to students: e.g., optics, the biology of the vision, but most importantly several concepts in chemistry, including redox reactions, coordination chemistry, and kinetics of chemical reactions; while also providing a creative opportunity for students to express themselves via the visual arts.[1] However, the photographic process no longer stands in this position, due to vast changes in both technology and EU legislation. Modern digital technology makes the elaborate photographic process redundant in everyday life. Furthermore, the legislation forbids students to work with carcinogenic and mutagenic substances, which rules out several commonly used photographic chemicals.[2] Yet, there are several reasons not to discard photography from the educational process. The analogue process, after all, still plays an important role in artistic photography. Nonetheless, the most important reason is the aforementioned overlap of both visual arts and natural sciences. In addition, analogue photographic processes have been studied since the 19th century, and therefore, there is an extensive methodology regarding them. The opportunity for students to express themselves may in turn play a role in creating a positive attitude toward chemistry.

The Links between Chemistry and Art

The chemistry-art interdisciplinary relationship is a quite common topic in the education of art majors. Several manuals on teaching art-linked chemistry courses have been introduced,[3,4] but only a few of them are focusing on photography.[5,6] However, regarding the application of art in chemistry education, only a few papers have been hitherto published. Stamovlasis, for instance, presented a series of experiments incorporating the chemical kinetics of analogue photography, which he recommends for use in chemistry, physics, history, and arts education.[7,8] A comprehensive guide to calotype—an old silver-based photographic process has been proposed by Rösch and Helmerdig.[9] Their research was focused on science skills' development among design students and conducted as a three-day-long interactive workshop. The students started the workshop with little knowledge of the process and ended it with enough experience to optimize the process in order to get the desired result. An educational use of cyanotype, a nonsilver process has been proposed by Lawrence

Received: November 22, 2022
Revised: April 17, 2023
Published: May 3, 2023

https://doi.org/10.1021/acs.jchemed.2c01089
J. Chem. Educ. 2023, 100, 2367−2372

and Fishelson[10] and also by Fiorito and Polo[11] (the latter applied later in this paper).

Attitudes toward Science and Art Subjects

Although it is often underestimated, creating a positive attitude toward the subject should be an important aim of every teacher. The research confirms a direct relation between students' attitudes toward science and their achievements in science subjects.[12,13] The process of attitude change depends on the methods and means chosen by the teacher during the education process. Certain methods, however, influence attitudes more strongly than others.[14,15]

Both experience and research confirm that science subjects are the less popular ones among students. An alarming trend has even been observed: the popularity of these subjects has been on a decline every year since the 1980s.[16] Reasons for this are most likely the lack of constructivism and motivation in the educational process. Science subjects are also very often perceived as purposeless and not applicable in everyday life.[17,18] Students' attitudes toward visual arts are generally considered positive. Students however tend to perceive art only superficially, as a mere depiction of reality, instead of learning the deep analysis artwork often requires. They also lack the opportunity to express themselves via art in school.[19]

Therefore, in order to help students gain new knowledge and develop positive attitudes toward such subjects, it is considered important to search for further interplays between natural sciences and art relevant for use in elementary and high-school education. Thus, a series of school experiments with photographic processes for such use have been proposed, with an emphasis on congruence with the curriculum and the safety of both procedures and chemicals. As the most convenient process for this use the cyanotype has been chosen.

Cyanotype: A Nonsilver Photographic Process

The cyanotype process is the oldest photographic process that does not use light-sensitive silver salts but, instead, uses iron compounds.[20] It was invented by the famous British astronomer Sir John Frederick William Herschel in 1842. It had not become particularly popular in artistic photography, but due to the low cost of the necessary materials it was quite common in making copies of technical drawings, therefore called *blueprints*.[10,11,20,21] Herschel himself used it as a way of copying his manuscripts. Moreover, several artists, such as Peter Henry Emerson, even despised its use in art.[21]

The most famous work using cyanotype was, however, the book *Photographs of British Algae: Cyanotype Impressions* (1843) by the British botanist and photography pioneer Anna Atkins. It is often considered the first book illustrated with photography and Anna Atkins herself is considered the first female photographer.[21] The book contains 398 tables with cyanotypice depictions of British algae and 14 pages of text.[22] In this research, the participants made cyanotypic photograms of plants, as Anna Atkins did.

The Chemistry Behind the Process

As it has already been stated, cyanotype uses the light-sensitivity of iron compounds. Namely, some complex iron(III) salts can be reduced to an iron(II) salt when exposed to UV light, if an oxidizable organic compound is present (eq I.). The iron(II) salt then reacts with potassium ferricyanide to form the well-known dark-blue pigment—Prussian blue (eq II). Thus, if a paper is treated with both the iron(III) salt and the potassium ferricyanide, and exposed to UV light afterward, a negative image emerges, since the exposed area of the paper turns blue and the unexposed area remains white.[11,21]

$$\mathrm{Fe^{III}} + \mathrm{org.(red.)} \xrightarrow{\text{UV light}} \mathrm{Fe^{II}} + \mathrm{org.(ox.)} \tag{I}$$

$$4\mathrm{Fe^{II}} + 3[\mathrm{Fe(CN)_6}]^{3-} \rightarrow \mathrm{Fe_4[Fe(CN)_6]_3} \tag{II}$$

The image is further developed and fixed in one step—by being submerged in water, which dissolves the remaining iron(III) salt and ferricyanide, leaving only the insoluble Prussian blue.[21]

The Material for Cyanotype

No special changes to a school lab need to be done to be able to make cyanotypes, apart from at least partially blinding the windows to prevent sunlight. The required chemicals are usually available but can be prepared from scratch as another experimental work. Any paper capable of standing up to washing is suitable for the process.[11]

Chemicals for the Cyanotype

Several iron(III) salts show light-sensitivity under UV light, but the best results are obtained with two: **ferric ammonium citrate** and **potassium ferrioxalate**.[11,23]

The structure of **ferric ammonium citrate** is shown in Figure 1. The stoichiometric ratio of ammonium and iron varies. However, the most suitable for the cyanotype process is the green form, containing about 14.5−16% of iron. The green ferric ammonium citrate is a dark green, very hygroscopic crystalline substance. As an example of its hygroscopicity, it absorbs water so rapidly that when the jar is open in a humid room the powder quickly becomes damp to the touch, the particles soon fuse together, and eventually the material becomes a semiliquid mass.[24−26] Despite its slight ammonia odor,[26] it is not considered a dangerous substance under EC regulation,[27] although it is sometimes listed as an irritant.[28] It is commercially available for a reasonable price.

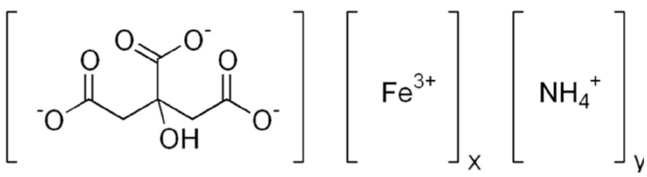


Figure 1. Ammonium ferric citrate. "X" and "Y" show the non-stoichiometric character of the compound.

Potassium ferrioxalate, the second reagent of choice, is a coordination compound, which contains the complex, light-sensitive ferrioxalate anion (Figure 2). The substance is harder

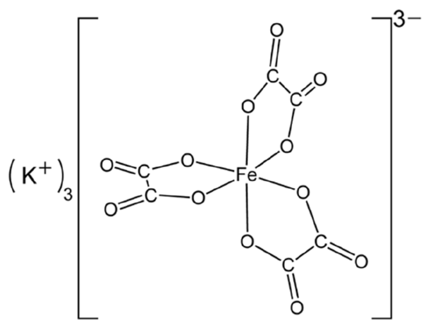


Figure 2. Potassium ferrioxalate.

to obtain commercially but has one great advantage in comparison to ammonium ferric citrate: it is not hygroscopic, even when exposed to humid air. Like the previous substance, it is of low toxicity.[29] It is also easy to prepare[30] even in school and its preparation, as shown later, acts as another convenient experimental lesson for students.[11]

Educational Potential of Cyanotype Process

The cyanotype is quite a convenient photographic process for use in chemistry education. The procedure is simple and does not need particular preparation or equipment. The coated paper does not require to be stored in darkness; only direct sunlight is to be avoided. The chemicals are either available or relatively easy to prepare from common laboratory chemicals. Both the process and the preparation of the reactants may act as an experimental lesson or part of a longer workshop. The process shows good results even without special skills. Students also found the resulting blue image quite appealing. The process also fits the high-school curriculum—it is a convenient demonstration of, e.g., redox processes and some concepts in coordination chemistry (ligand substitution etc.). Another advantage is the fact that part of the process takes place outside—outdoor education has been confirmed as a useful tool to make lessons more attractive.[31,32]

Implementation

A set of three experimental lessons for students have been composed, one for each level of education (ISCED 1, 2, 3). Each one has been adjusted to the students' level of knowledge and skills and was tested on students from various places in Slovakia, with details shown in Table 1. A total number of 117 students participated in the research. Students at each level worked in pairs. ISCED 2 and 3-level students used worksheets with step-by-step instructions and tasks (see the Supporting Information).

Table 1. Number of Students by Level and School Type Who Participated in the Research

Level of education	Number of students	School type and location
ISCED 1	55	Various elementary schools in town of Martin, Slovakia (aged 6−8)
	17	Composite-class rural elementary school in Sklené, Slovakia (aged 6−10)
ISCED 2	15	7th grade (aged 12−13) of an elementary school in Bratislava, Slovakia
	10	2nd grade (aged 12−13) of eight-year high school in Bratislava, Slovakia
ISCED 3	20	2nd grade (aged 16−17) of four-year high school in Bratislava, Slovakia

ISCED 1 Pupils

It was taken into consideration that the ISCED 1 pupils have not attended any chemistry classes yet. The lesson was composed of a short introduction to the history of cyanotypes and the making of the cyanotypic photograms of plants. Pupils were told to prepare pressed flowers and plants, while the teacher took care of preparing the solutions and coating the paper. The paper was coated with the mixture of green ferric ammonium citrate and potassium ferricyanide the day prior to the lesson and dried overnight in a dark place. After the introduction, the teacher explained the procedure of placing plants or other objects onto the coated paper and then exposing it to sunlight. The pupils then proceeded to arrange the pressed flowers and kept them in place with a sheet of plexiglass (clip frames were used for the purpose). Then the group headed outside to expose the paper to sunlight and after 4−5 min returned indoors in order to fix the image with running water. The images were left to dry afterward.

ISCED 2 Pupils

On the ISCED 2 level, the procedure was extended with the pupils mixing the solutions together and coating the paper. The other steps remained the same as on the previous level. However, the introduction and the history of cyanotype was much shorter in order to save time and included a demonstration of Prussian blue formation with iron(II) sulfate, iron(III) sulfate, and potassium ferricyanide. It was shown that the potassium ferricyanide only forms Prussian blue with iron(II) salts. However, it is also explained, that it is possible to reduce some iron(III) salts, which happens in this experiment.

Afterward, the pupils work according to the instructions in their handouts (see the Supporting Information). The bulk solutions of ferric ammonium citrate and potassium ferricyanide are mixed and spread onto the paper using a brush. Then, without further drying, the pupils continued the same way as ISCED 1 students.

ISCED 3 Pupils

On the ISCED level 3, the history of photography has been omitted entirely and the introduction started directly with the chemistry behind the cyanotype, including the Prussian blue formation demonstration, as on previous level (see the Supporting Information).

In the first step, the potassium ferrioxalate was synthesized. To do this, solutions were prepared according to Table 2. The preparation of solutions A and B with the subsequent synthesis of potassium ferrioxalate follows the standard procedure from the literature.[30]

Table 2. Preparation of the Solutions for the Potassium Ferrioxalate Synthesis

Beaker	A[30]	B[30]	C
Water	15 mL	45 mL	10 mL
Substance	1.1 g of iron(III) sulfate	1.1 g of potassium oxalate monohydrate	1.4 g of potassium ferricyanide
		0.76 g of oxalic acid dihydrate	

Under some conditions the solution iron(III) sulfate does not fully dissolve, which should not prevent proceeding to the next step. Then the procedure continues by adding sodium hydroxide into solution A, which results in iron(III) hydroxide precipitation (eq III). The precipitate is further filtered and washed with distilled water on Büchner funnel. The precipitate is then added into the preheated solution B, where it reacts with the potassium oxalate, while the oxalic acid adjusts the pH of the solution (eq IV).

$$Fe^{3+} + 3OH^- \rightarrow Fe(OH)_3\downarrow \qquad (III)$$

$$2Fe(OH)_3 + 3K_2C_2O_4 + 3H_2C_2O_4 \rightarrow 2K_3[Fe(C_2O_4)_3] + 6H_2O \qquad (IV)$$

The procedure results in a bright green solution of potassium ferrioxalate, which can be directly mixed with solution C to form the sensitizing agent. After trying out several concen-

https://doi.org/10.1021/acs.jchemed.2c01089
J. Chem. Educ. 2023, 100, 2367−2372

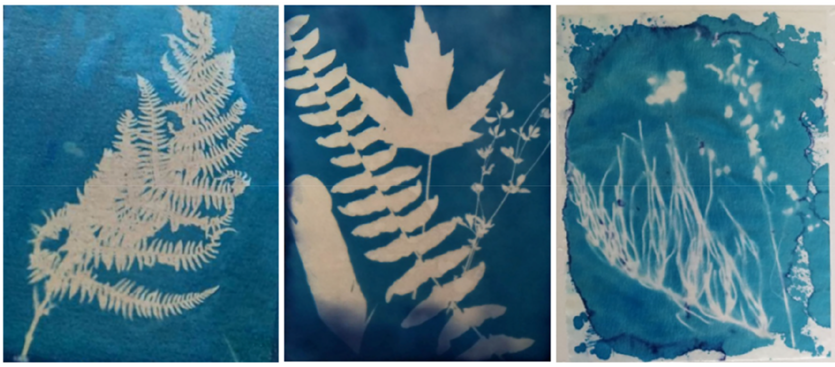


Figure 3. Cyanotypes created by the participants. Left to right: ISCED 1, ISCED 2, and ISCED 3. Reproduced with the permission of students who participated in the workshop.

Table 3. Statistical Measures of the Results

	ISCED 2				ISCED 3			
	Art		Nat. sciences		Art		Nat. sciences	
	Before	After	Before	After	Before	After	Before	After
Arithmetic mean	1.303	1.376	1.765	1.836	1.433	1.483	1.750	1.891
Median	1.30	1.40	1.70	2.00	1.50	1.65	1.85	2.00
Mode	1.50	1.00	1.60	2.00	1.50	1.70	2.20	2.10
Standard Deviation	0.491	0.599	0.485	0.408	0.731	0.636	0.497	0.488
Norm. Distr.[34]	norm.	norm.	norm.	norm.	norm.	norm.	norm.	norm.
Correlation Coefficient (α = 0.01)	0.756		0.730		0.887		0.762	
Statistical significance	no	no	no	no	no	no	no	no
Effect Size d	0.113		0.126		0.058		0.233	
Interpretation[35]	no effect		no effect		no effect		***small effect***	

trations of potassium ferricyanide, the solution given in the table has been chosen to be the most convenient for this procedure. The concentration of this solution varies in literature.[11,33] The sensitizing agent is then spread onto the paper and the procedure follows as stated at the previous level.

Student Cyanotype Images

With each group of participants, the final results were the cyanotype images, some of them very creatively made (Figure 3). Students used a range of plants, including some houseplants, like *Nephrolepis*; some wild European plants, like *Dryoptheris, Acer, Equisetum* and others. Some students have chosen to include feathers, seeds and rocks in their design (Figure 3 in the middle).

Assessment of Student Attitudes

In order to determine younger pupils' (ISCED 1) view of the lesson, they were given a blank sheet of paper to fill-in with their feedback. They were prompted to state what they thought of the lesson. The results were assessed qualitatively. Qualitative data were not collected from the ISCED level 2 and 3 students.

However, the main focus of the research was to determine an attitude change before and after the series of lessons. A questionnaire was administered to ISCED 2 and ISCED 3 students in order to assess their attitudes toward art and chemistry before and after the experimental lesson (see the Supporting Information). The questionnaire consisted of 20 scaled items, 10 focused on art, and 10 on natural sciences. It was distributed to the students before (pretest) and a week after the lesson (post-test). Statistical methods were used in order to interpret the results. Each group of answers (natural sciences and arts) assessed separately and compared.

■ RESULTS

The statistical results were both qualitative and quantitative. Qualitative research has shown overall positive view among ISCED level 1 pupils, with only two feedbacks calling the lesson "too long". Most of the other results were positive, mostly stating that they liked the image and the process.

Quantitative results are summarized in Table 3. Descriptive statistics implies some positive attitude change, namely the mean and median, which shows increase in average score. In all data sets the distribution was normal according to D'Agostino-Pearson test of normality. Therefore, parametric tests for correlation (Pearson) and significance (Student and Cohen) were used. No significance of the change has been proven in the Student's t-test. However, a small effect was shown by Cohen's d test in ISCED 3 students' attitudes toward natural sciences.

Modifications to the Experiment

In order to save time, modifications have been made to the process after testing it in the school conditions. It is better to prepare some bulk solutions prior to the lesson. A paper already cut to size (18 × 28 cm) was bought, so students would not have to cut it themselves. In the potassium ferrioxalate synthesis, there is no need to scrape the precipitate from the filter paper: it is better to add the whole paper into solution B and remove it after all the precipitate dissolves.

■ CONCLUSION

The goal of the research was to introduce a photographic process to students at various levels of education, which was achieved using a nonsilver photographic process−cyanotype process. The experimental lessons were not assessed, despite

https://doi.org/10.1021/acs.jchemed.2c01089
J. Chem. Educ. 2023, 100, 2367−2372

the fact that the students filled in worksheets. The aim of the lessons was rather to enhance the interdisciplinary relationships between art and natural sciences and help students develop their creativity and laboratory skills during chemistry classes.

The results of the students' view and attitude assessment were generally positive, although the actual attitude change was arguable. However, a small effect of the visually attractive and interdisciplinary lesson on attitude change has been shown. That implies, this lesson has the potential to improve students' attitudes. Nonetheless, to achieve a stronger effect, implementing more visually attractive lessons like these is advised.

The students reacted to the lessons almost exclusively in a positive way, highlighting the opportunity to express themselves via visual arts while simultaneously learning new concepts in chemistry. They found both the procedure and the results quite interesting, some of them even stating that this is the first time they have actually enjoyed a chemistry lesson.

Hazards

Potassium ferricyanide is not listed as hazardous substance. Ferric ammonium citrate, iron(II) sulfate, and oxalic acid are hazardous in the case of skin and eye contact (irritant). Iron(III) sulfate is hazardous when swallowed and in case of skin and eye contact. Potassium oxalate is a toxic substance (acute toxicity cat. 4) and an irritant. Sodium hydroxide is corrosive. Therefore, only the teacher is allowed to work with it under EU regulations.

The laboratory experiment on ISCED 1 level requires no special precautions, as the paper is already sensitized by the teacher. On ISCED 2 level, pupils are required to use lab coats, gloves and protective goggles. The same precautions are required on ISCED 3 level, but since the students heated the solutions themselves, extra caution is advised. The students were instructed not to eat nor drink in the lab and not to touch any of the chemicals with bare hands. Standard safety procedures were introduced to the students prior to the lesson.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c01089.

ISCED 2 level student handout (PDF, DOCX)
ISCED 3 level student handout (PDF, DOCX)
Instructor notes for ISCED 2 (PDF, DOCX)
Instructor notes for ISCED 3 (PDF, DOCX)
Questionnaire (PDF, DOCX)

■ AUTHOR INFORMATION

Corresponding Author

Alexander Kmet' – *Comenius University in Bratislava, Department of Didactics in Science, Psychology and Pedagogy, Faculty of Natural Sciences, Bratislava, Slovakia 84215*; orcid.org/0000-0003-0593-2627; Email: kmet45@uniba.sk

Authors

Anna Drozdíková – *Comenius University in Bratislava, Department of Didactics in Science, Psychology and Pedagogy, Faculty of Natural Sciences, Bratislava, Slovakia 84215*

Soňa Nagyová – *Comenius University in Bratislava, Department of Didactics in Science, Psychology and Pedagogy, Faculty of Natural Sciences, Bratislava, Slovakia 84215*

Peter Ikhardt – *Comenius University in Bratislava, Department of Didactics in Science, Psychology and Pedagogy, Faculty of Natural Sciences, Bratislava, Slovakia 84215*

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.jchemed.2c01089

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors would like to acknowledge participation of the students and teachers of elementary and high schools in Martin, Sklené, and Bratislava, Slovakia, help from the employees of the Slovak National Museum in Martin, Slovakia, and the Faculty of Natural Sciences of Comenius University in Bratislava, Slovakia. A special thanks goes to Hilda Vaněková and Julián Vrábel for reviewing the manuscript's English.

■ REFERENCES

(1) Persing, K. M. A High-school Course in Photography. *J. Chem. Educ.* **1931**, *8* (8), 1587.

(2) European Parliament and Council. *Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on Classification, Labelling and Packaging of Substances and Mixtures, Amending and Repealing Directives 67/548/EEC and 1999/45/EC, and Amending Regulation (EC) No 1907/2006*; European Parliament and Council: Bruxelles, 2008.

(3) Nivens, D. A.; Padgett, C. W.; Chase, J. M.; Verges, K. J.; Jamieson, D. S. Art, Meet Chemistry; Chemistry, Meet Art: Case Studies, Current Literature, and Instrumental Methods Combined To Create a Hands-On Experience for Nonmajors and Instrumental Analysis Students. *J. Chem. Educ.* **2010**, *87* (10), 1089–1093 and citations therein.

(4) Hemraj-Benny, T.; Beckford, I. Cooperative and Inquiry-Based Learning Utilizing Art-Related Topics: Teaching Chemistry to Community College Nonscience Majors. *J. Chem. Educ.* **2014**, *91* (10), 1618–1622.

(5) Greenberg, B. Art in Chemistry: An Interdisciplinary Approach to Teaching Art and Chemistry. *J. Chem. Educ.* **1988**, *65* (2), 148–150.

(6) Sattar, S. The Chemistry of Photography: Still a Terrific Laboratory Course for Nonscience Majors. *J. Chem. Educ.* **2017**, *94* (2), 183–189.

(7) Stamovlasis, D. Teaching Photography: Interplay between Chemical Kinetics and Visual Art. *Chem. Educ. Res. Pract.* **2003**, *4* (1), 55–66.

(8) Stamovlasis, D. Teaching Photography: an Interdisciplinary Theme in Science, Technology and Art. *Proceedings of the IOSTE Symposium in Southern Europe* **2001**, 2–9.

(9) Rösch, E.; Helmerdig, S. Understanding Photography as Applied Chemistry: Using Talbot's Calotype Process To Introduce Chemistry to Design Students. *J. Chem. Educ.* **2017**, *94* (7), 916–921.

(10) Lawrence, G. D.; Fishelson, S. Blueprint Photography by the Cyanotype Process. *J. Chem. Educ.* **1999**, *76* (9), 1216A.

(11) Fiorito, P. A.; Polo, A. S. A New Approach toward Cyanotype Photography Using Tris-(oxalato)ferrate(III): An Integrated Experiment. *J. Chem. Educ.* **2015**, *92* (10), 1721–1724.

(12) Papanastasiou, E. C.; Zembylas, M. Differential Effects of Science Attitudes and Science Achievement in Australia, Cyprus, and the USA. *Int. J. Sci. Educ.* **2004**, *26* (3), 259–280.

(13) Cukrowska, E.; Staskun, M. G.; Schoeman, H. Attitudes towards Chemistry and their Relationship to Student Achievement in Introductory Chemistry Courses. *S. Afr. J. Chem.* **1999**, *52*, 8−15.
(14) Walczak, D. E.; Walczak, M. M. Do Student Attitudes toward Science Change during a General Education Chemistry Course? *J. Chem. Educ.* **2009**, *86* (8), 985−991.
(15) Leavers, D. R. A Course which Changed the Attitudes of Students towards Science. *J. Chem. Educ.* **1975**, *52* (12), 804.
(16) Koballa, T. R.; Glynn, S. M. Attitudional and Motivational Constructs in Science Learning. In *Handbook on Research of Science Education*; Lawrence Erlbaum Associates Inc. Publishers: NJ, 2007, 75−102.
(17) Prokop, P.; Tuncer, G.; CHUDÁ, J. Slovakian Students' Attitude towards Biology. *Eurasia. J. Math. Sci. T.* **2007**, 3 (4), 287−295.
(18) Cheung, A. Students' Attitudes toward Chemistry Lessons: The Interaction Effect between Grade Level and Gender. *Res. Sci. Educ.* **2009**, *39* (1), 75−91.
(19) Denac, O.; ČAgran, B.; Denac, J.; Kafol, B. S. Students' Attitudes towards Arts and Cultural Learning in the Slovenian Educational System. Zagreb, Croatia. *Croat. J. Educ.* **2013**, *15* (3), 39−72.
(20) Ware, M. Herschel's Cyanotype: Invention or Discovery? *Hist. Photogr.* **1998**, *22* (4), 371−379.
(21) Ware, M. *Cyanomicon: History, Science and Art of Cyanotype: Photographic Printing in Prussian Blue*; University of Manchester, Manchester, UK, 2020. https://unblinkingeye.com/Cyanomicon.pdf.
(22) Saska, H. Anna Atkins: Photographs of British Algae. *Bulletin of the Detroit Institute of Arts* **2010**, *84* (1), 8−15.
(23) Tomášek, Z. *Fotografické Chemikálie*; Merkur: Turnov, Czech Republic, 1982.
(24) Tenne, D.; Bogoslavsky, B.; Bino, A. Ferric Ammonium Citrate - What's in It? *Eur. J. Inorg. Chem.* **2015**, *2015* (25), 4159−416.
(25) Kruse, H.; Mounce, H. Crystalline Ferric Ammonium Citrate Compounds. United States Patent US98,204A, 1949.
(26) National Center for Biotechnology Information. *Ferric Ammonium Citrate*. https://pubchem.ncbi.nlm.nih.gov/compound/Ferric-ammonium-citrate (accessed 2022-08-12).
(27) Honeywell International, Inc. *Ferric Ammonium Citrate − SDS*. https://msds-resource.honeywell.com/ehswww/hon/result/result_single.jsp?P_LANGU=E&P_SYS=1&C001=MSDS&C997=C100%3BC%2BC101%3BSDS_CZ%2BC102%3BCZ%2B3400&C100=*&C101=*&C102=*&C005=000000020660&C008=&C006=HON&C013 (accessed 2022-08-12).
(28) Jacquard Products. *Ferric Ammonium Citrate − SDS*. https://uwaterloo.ca/fine-arts/sites/ca.fine-arts/files/uploads/files/ferric-ammonium-citrate_2018-02-07.pdf (accessed 2022-08-26).
(29) Pfaltz & Bauer. *Potassium Ferric Oxalate Trihydrate − SDS*. https://www.pfaltzandbauer.com/SDSFile.ashx?ItemCode=P22950 (accessed 2022-08-26).
(30) Saritha, A.; Raju, B.; Ramachary, M.; Raghavaiah, P.; Hussain, K. Synthesis, Crystal Structure and Characterization of Chiral, Three-dimensional Anhydrous Potassium Tris(oxalato)ferrate(III). *Physica B* **2012**, *407*, 4208−4213.
(31) Martin, P. Teacher Qualification Guidelines, Ecological Literacy and Outdoor Education. *J. Outdoor Environ. Educ.* **2008**, *12* (2), 32−38.
(32) Johns, R.; Pontes, R. Parks, Rhetoric and Environmental Education: Challenges and Opportunities for Enhancing Ecoliteracy. *J. Outdoor Environ. Educ.* **2019**, *22* (1), 1−19.
(33) Wade, K. Alternative Photographic Processes: *A Resource Manual for the Artist, Photographer, Craftsperson*; Morgan & Morgan, 1978.
(34) D'Agostino, R.; Pearson, E. S. Tests for Departure from Normality. Empirical Results for the Distributions of b_2 and $\sqrt{b_1}$. *Biometrika* **1973**, *60* (3), 613−622.
(35) Cohen, J. Statistical Power Analysis. *Current Directions in Psychological Science* **1992**, *1* (3), 98−101.