Chemistry Education Research and Practice

PAPER

Check for updates

Cite this: *Chem. Educ. Res. Pract.*, 2018, **19**, 558

Improving the interest of high-school students toward chemistry by crime scene investigation

A. Basso, *[a] C. Chiorri, [b] F. Bracco, [b] M. M. Carnasciali, [a] M. Alloisio [a] and M. Grotti *[a]

Received 29th November 2017, Accepted 23rd February 2018

DOI: 10.1039/c7rp00232g

rsc.li/cerp

Improving the interest of high-school students towards chemistry (and science in general) is one of the goals of the Italian Ministry of Education. To this aim, we designed a context-based activity that actively involved students in six different laboratory experiences interconnected by a case study of the murder of Miss Scarlet, from the famous game Clue. Key points of the activity were: the interest aroused by the subject of crime scene investigation; the direct involvement of the students in all stages of the work (from the realization of the experiments to the resolution of the case); the use of a multidisciplinary approach for addressing a complex scientific problem; the work in chemical laboratories with modern instrumentation; the team work and the supervision by young tutors. To verify the hypothesis that such a multidisciplinary activity could foster the interest for the discipline, an evaluation was performed using a self-report questionnaire designed to assess changes in the situational interest raised by the internship. It was found that the activity significantly increased interest and attitude toward chemistry, mainly for students with lower scores in pleasure for the study of chemistry, self-efficacy and self-concept in chemistry.

Introduction

Currently, Europe faces a shortfall in science-knowledgeable people at all levels of society and the economy (Hazelkorn *et al.*, 2015). Over the last few decades, there has been an increase in the number of students leaving formal education with science qualifications. However, there has not been a parallel increase in the number of those interested in science or convinced that school science will have an impact on their career chances (Jøberg and Schreiner, 2010). Remarkably, the more developed the country, the less the overall interest. Many international reports have identified the potential shortage of human resources in key scientific professions (Forsthuber *et al.*, 2011; Gago *et al.*, 2015) and called for modernizing science teaching in school, in order to raise the motivation of pupils, to increase their interest in science, and to increase attainment levels at the same time.

Improving science education has been high on the political agenda of many European countries since the end of the 1990s. Over the last decade, in particular, a great number of programs and projects have been set up to encourage more students to study science by boosting their interest (Forsthuber *et al.*, 2011). Although it has been recognized that science teaching at primary school has a strong long-term impact, maintaining or recovering high levels of interest is still important at the secondary level, when the likelihood that students will become disengaged with science increases (Dillon and Osborne, 2008).

Many researchers have highlighted that students' low or declining interest in science is largely due to its presentation as a collection of detached, de-contextualized, and value-free facts that are not connected to their own experiences (Sjøberg, 2002; Osborne *et al.*, 2003; Aikenhead, 2005). Therefore, a potential way of improving student motivation and interest in the subject is to use social and real-life contexts and practical applications as the starting point for the development of scientific ideas (Bennett *et al.*, 2007). This method, referred to as "context-based science teaching" or a "science–technology–society approach", is considered to increase students' motivation in scientific studies, and possibly lead to improved scientific achievement (Irwin, 2000; Lubben *et al.*, 2005; Bennett *et al.*, 2007). The effectiveness of a "context-based" learning environment in stimulating pupils' interest in chemistry has also been reported (Henderleiter and Pringle, 1999; Gutwill-Wise, 2001; Pernaa and Aksela, 2011; O'Dwyer and Childs, 2014).

In Italy, the project "Scientific Degrees Plan", launched in 2004 and currently ongoing, successfully integrated various private and public institutions, mainly universities, with the aim of promoting science teaching in secondary schools and increasing the number of participants in chemistry, physics, and mathematics degree programs. In this frame, an original "context-based science-teaching" activity has been designed at the Department of Chemistry and Industrial Chemistry of the University of Genova in order to promote the interest of

[a] *Department of Chemistry and Industrial Chemistry, University of Genova, Italy. E-mail: andrea.basso@unige.it, marco.grotti@unige.it*
[b] *Department of Educational Sciences, University of Genova, Italy*

high-school students toward chemistry, by exploiting the great attraction of teenagers for crime scene investigation.

Teaching science through mystery helps students to develop their investigative skills and explore some fascinating hidden science; recently, the initiative "Teaching Enquiry with Mysteries Incorporated" (TEMI) was founded by the European Community with the aim of transforming the way in which Science, Technology, Engineering, and Mathematics (STEM) subjects are taught in classrooms (McOwan *et al.*, 2016). On the other hand, forensic chemistry problems have often been used to stimulate interest in specific chemistry subjects, such as density determination (Saccocio and Carroll, 2006), colorimetric analysis (Ravgiala *et al.*, 2014), thin layer chromatography (Hasan *et al.*, 2008), liquid chromatography (Beussman, 2007), and gas chromatography (Henck and Nally, 2007), or even niche subjects such as Energy-Dispersive X-ray Fluorescence Spectrometry (Palmer, 2011) or Laser Induced Breakdown Spectroscopy (Randall *et al.*, 2013). Laboratory activities associated with these forensic problems, however, were restricted to specific subjects, offering a narrow view of the chemistry world and therefore not being suitable to induce a change in the interest of the students for the discipline. In order to overcome this drawback, instead of specializing in a specific technique, we designed an activity able to include and interconnect all branches of chemistry in a single experience, in order to provide a general overview of what chemistry is and what it can be used for. Moreover, in order to stimulate the interest of the students, we decided to address the following points: (a) the attention aroused by the subject of crime scene investigation and the "playful setting" of the activity; (b) the direct involvement of the student in all phases of the work, from the realization of the experiments to the resolution of the case; (c) the use of a multidisciplinary approach for addressing a complex scientific problem; (d) the opportunity to work in chemical laboratories with modern instrumentation; and (e) the team work and the supervision by young tutors.

After six years of this project, involving about 500 students from various Liguria and southern Piedmont (North Italy) secondary schools, we present here the activity in detail, and its evaluation by a questionnaire.

Leading idea of the activity

"Who killed Miss Scarlet?" The question appeared suddenly at the entrance of the Department of Chemistry and Industrial Chemistry, University of Genova, besides the outline of a corpse, the labels of forensics and the famous strip "CSI – Do not cross this line." In this way, students were dynamically introduced into a "context-based science-teaching" activity, a case study of forensic chemistry: the murder of Miss Scarlet, from the famous game "Clue". Who killed the beautiful Kassandra Scarlet, who fled hastily from work and was found dead in a car on fire? Her brother Jacob Green, the sole heir of the family property in the event of her death, or the stalker Jack Mustard? The mysterious colleague Eleanor Peacock, the jealous partner Victor Plum, or friend Diane White, envious of her beauty?

To find out, twenty-five students per week, divided into teams of five and supervised by young tutors, initially investigated the crime scene, using the techniques of the Scientific Police to detect fingerprints and traces of blood; then they took off several artefacts (pieces of cloth, locks of hair, dust and metal fragments) that were the subject of investigations carried out in the various sections of the department. These investigations allowed students to come into direct contact with different aspects of chemistry and with modern equipment and technologies. Alongside the specific objectives of the various experiences, closely related to the murder case, students had the opportunity to delve into more general topics and see how chemistry is also central in everyday life. The five-day activity ended with a presentation by the students, through which they could describe the applied methodologies and collected data, discuss the deduced information, and substantiate the identification of the culprit.

Detailed description of the activity

Presentation and recruitment test

Upon arrival and gathering at the entrance of the department, close to the recreation of the crime scene, students were accompanied by a staff member into a classroom, where a short presentation of the objectives and conditions of the activity took place. Then, students were divided into teams of five (classmates were split into different groups, in order to promote the exchange of experiences and teamwork) and subjected to the recruitment test (Appendix 2). It was a short test with multiple choice questions on general forensic issues, aimed to foster team building and to introduce the students into the leading topic. Purposely, some questions were rather difficult for a high school level, as the recruitment test was not used to define the level of knowledge of the participants, but for starting the teams up, by facilitating introductions, encouraging students to share their thoughts and letting all contribute to the team and experience the strength of teamwork. Moreover, this preparatory activity proved very useful to focus the students' attention on scientific reasoning and to shift their praxis from individualism to cooperation. Finally, a discussion driven by a staff member on the right answers of the recruitment test provided useful information on the general aspects of the scientific investigation, highlighting the chemistry behind it, even when the questions were not strictly related to the case.

Laboratory experiments

Each group participated in six half-day experiments, according to a specific workplan (Appendix 3). The order of experiments was not relevant for the case study, as information from each experiment was independent and not conclusive itself. Students were directly involved in each experiment and supervised by young MSci or PhD students (tutors) in order to encourage their active participation. Experiments comprised all branches of chemical science: forensic, analytical, organic, physical, industrial, and inorganic chemistry. A summary of activities and related objectives and techniques is shown in Table 2.

Forensic analysis consisted of the examination of bloodstains (by a luminol test) and fingerprints (by a ninhydrin test) and involved the students in routine techniques of crime scene investigation. These experiments were useful to critically highlight the difficulties that arise depending on the different materials analyzed and as a result of possible false positives, as well as to discuss more general issues, like the organic reactions characterized by light emission and blood constituents. The experience in the analytical chemistry laboratory introduced the students to the concept of qualitative and quantitative analysis, through the identification of an unknown white powder by classical qualitative tests and flame tests, as well as the quantification of magnesium in the suspects' hair samples by modern atomic spectrometry. In the industrial chemistry laboratory, qualitative analysis of fabrics discovered on the crime scene was performed. Here, dissolution, distillation and combustion tests and optical microscope observations stimulated the discussion on the comparative properties of natural and synthetic fabrics, structure–property relationships in polymers and plastic recycling. The organic chemistry experience was aimed at identifying the composition of an essential oil, collected from the crime scene and related to the profession of one of the suspects. Steam distillation, liquid–liquid extraction and gas-chromatographic analysis were carried out by students, who could also discuss about separation and purification techniques, natural substances, and small molecule–receptor interactions. Analysis of debris by X-ray diffraction in the physical chemistry laboratory allowed the comparison of an unknown sample with materials used in construction and restoration, stimulating the discussion on crystals and their properties. Finally, elemental and metallographic analysis of metal fragments, besides the identification of the murder weapon, served to discuss about metals and alloys and illustrate the techniques for their characterization. Further details on each experiment are available in Appendix 3.

Team briefings and the final presentation

Two short briefings after the first three experiences and at the end of the laboratory activity were designed, so that each team could discuss the applied methodologies and the obtained experimental data. Results from each experiment were relevant for the solution of the murder case, but never conclusive, indicating one or more suspects or exonerating others. So, the students were asked to collectively consider all the scientific evidence in order to come to a conclusion. Team briefings were supervised by tutors, to ensure the scientific correctness of the discussion. Finally, the activity ended with a presentation by the students of the collected data and the identification of the culprit, to be repeated in their classrooms.

This final task was an opportunity to highlight their creativity and imagination, as well as the enthusiasm with which they have dealt with the investigation.

Effectiveness of the activity

In order to test whether this activity was effective in improving the situational interest of the students towards chemistry, an evaluation was performed in 2017. It involved 84 students, which differed by gender (62% females; 38% males), grade (grade 10: 9.5%; grade 11: 81%; grade 12: 9.5%) and school type (high school: 83%; technical institute: 17%). A self-report questionnaire (Table 1) was administered and anonymously completed by the students. The item content was adapted from the Italian versions of the Self-Description Questionnaire (Marsh, 1990; Camodeca *et al.*, 2010), the PISA questionnaires (OECD, 2015), and the model developed by Wigfield and Eccles (2000). Data obtained before and after the activity could be paired by inviting the students to use a self-generated alphanumeric identification code. The questionnaire included 20 items that asked the students to rate how accurately each statement described them on a 7-point scale (from "not at all" to "completely"; but see Table 1 for different anchors for items 18–20). We opted for the self-report questionnaire rather than other methods (*e.g.*, interviews) because we wanted to rely on validated tools and limit any possible bias by researchers in evaluating the effects of the activity. Informed, written consent from the participants' parents and the participants themselves was obtained before data collection. Data were collected confidentially following the Ethical Principles of Psychologists and Code of Conduct (American Psychological Association, 2010), which paralleled the recommendations by Taber (2014) for this journal.

Questions 1–7 were aimed to assess the situational interest (Hidi and Renninger, 2006; Linnenbrink-Garcia *et al.*, 2010), considering both feeling-related (1–3) and value-related (4–7) valences (Schiefele, 1991). In order to evaluate possible changes due to the activity, these questions were delivered immediately

Table 1 Questionnaire

Item	Question
1	I am fascinated by Chemistry
2	I chose to take the internship because I'm really interested in the topic
3	I am really excited about taking this activity
4	I am really looking forward to learning more about Chemistry
5	I think the field of Chemistry is an important discipline
6	I think that the field of Chemistry will be important for me to know
7	I think that the field of Chemistry will be worthwhile for me to know
8	When I do Chemistry, I sometimes get totally absorbed
9	Because doing Chemistry is fun, I wouldn't want to give it up
10	Chemistry is important to me personally
11	Most people can learn to be good at Chemistry
12	You have to be born with the ability to be good at Chemistry
13	I'm confident that I can do an excellent job on my Chemistry tests
14	I'm certain I can understand the most difficult material presented in Chemistry texts
15	I'm confident I can understand the most complex material presented by my Chemistry teacher
16	I'm confident I can do an excellent job on my Chemistry assignments
17	I'm certain I can master the skills being taught in my Chemistry class
18	How good do you think you are in Chemistry? (not good – very good)
19	For me, Chemistry is... (very difficult – very easy)
20	Compared to your classmates, how good do you think you are in Chemistry? (the worst – the best)

Table 2 Laboratory experiments with related objectives and methodologies

Field	Activity	Objectives	Techniques	Discussion issues
Forensic chemistry	Examination of blood stains and fingerprints	Introduce the student in routine analysis carried out on the crime scene	Luminol test; ninhydrin test	Organic reactions characterized by light emission; blood and its constituents
Analytical chemistry	Qualitative and quantitative analysis of magnesium	Introduce the concepts of qualitative and quantitative analysis	Flame test; colorimetric assays; atomic absorption spectrometry	Sample handling; classic and instrumental analysis; atom structure
Industrial chemistry	Qualitative analysis of fabrics	Compare the properties of natural and synthetic fabrics	Dissolution, distillation and combustion tests; optical microscopy	Natural and synthetic fabrics; polymers and their properties; plastic recycling
Inorganic chemistry	Elemental and metallographic analysis of metal fragments	Introduce the notion of metal and alloys and their characterization	X-ray fluorescence; scanning electron microscopy	Analysis of metal surfaces; spectroscopic methods
Organic chemistry	Determination of the composition of an essential oil	Introduce the use of separation and purification techniques	Steam distillation; liquid–liquid extraction; gas-chromatography	Natural substances; small molecule–receptor interactions
Physical chemistry	Crystallographic analysis of debris	Introduce the properties of materials used in construction and restoration	X-ray diffraction	Crystals and X-ray diffraction; chemistry for cultural heritage

before and after it. The other questions were administered only before the activity, to assess the pleasure for the study of chemistry (8–10), beliefs about chemistry (11–12), self-efficacy in chemistry (13–17) and self-concept in chemistry (18–20). The items from 8 to 20 were not administered after the experience also because the activity aimed at increasing the situational interest, while the pleasure for the study of chemistry, the beliefs, self-efficacy, and self-concept in chemistry are constructs that were not directly addressed by the internship. Moreover, they are based on items focused on past experiences of study, rather than the current experience at the end of the activity, and whose change is supposed to take place over a long time.

A Wilcoxon test was carried out to test changes in the scores of questions 1–7. After correction for multiple comparisons of the *p*-value to control for false discovery rate, the test revealed a significant ($p < 0.001$) change in the scores before and after the experience for questions 1–3. These items are related to the feeling-related situational interest, which refers to the feelings (*e.g.* enjoyment, involvement) that are associated with the subject, while the value-related interest refers to the attribution of personal significance and importance (Schiefele, 1991). Since there was a substantial correlation among the scores of these three items (mean correlation before the experience: 0.66; mean correlation after the experience: 0.52), the scores of these items were summed to yield a single positive attitude toward the chemistry score (Cronbach's alpha: 0.85 and 0.76, before and after the experience, respectively). These scores allowed us to detect significant changes in each single student using the Reliable Change Index (Jacobson and Truax, 1991), and a new variable (change *vs.* no change) was created. Twelve (14.2%) students showed a significant increase in scores (and, consequently, in their positive attitude toward chemistry), while no student showed a significant decrease. Then, the association of this new variable with the issues assessed by questions 8–20 was investigated using multi-level linear multiple regression models, which also included as covariates gender, grade, and school type. The details of the statistical analysis results are reported in Appendix 1.

Concerning the pleasure for the study of chemistry, two significant effects were found: the change in the interest (-0.78; $p < 0.05$) and the school type (+1.07; $p < 0.01$). The first result means that the students who increased their interest after the activity (hopefully, due to the activity) had lower pleasure for the study of chemistry before the experience than the others, which would indicate a good effectiveness of the proposed activity. In fact, the motivational trigger for this activity was due to its playful and emotionally engaging nature. It is possible that this characteristic had a relevant effect on the students who had a (relatively) poorer motivation for the chemistry and, consequently, a lower pleasure. The activity seemed then able to move them from a poor and extrinsic motivation ("I study it because I have to") to a motivation based on incentives ("I study it because I am having fun"). On the other hand, the students that already had an intrinsic motivation towards chemistry ("I study it because I like it") were less prone to show potential positive effects due to emotions triggered by the playful context. The incentive based on positive emotions is particularly effective in those who have a poor motivation, while its effects are mild or even absent in students who already have an intrinsic motivation, who find the pleasure in the subject itself.

The second result indicates a greater pleasure for the study of chemistry for students from technical institutes compared to high-school students, but the implications of this result are beyond the purpose of this work.

Concerning the beliefs about chemistry, no significant effect was found, while both self-efficacy and self-concept in chemistry were significantly related to the change in the interest (-0.62 and -0.51; $p = 0.055$ and $p = 0.030$ respectively). Again, these results suggest that the improvement in the interest occurred in students with lower self-efficacy and self-concept in chemistry than the others.

Conclusions

As the world becomes more inter-connected and competitive and the research and technological know-how expand, new opportunities along with more complex societal challenges arise. Overcoming these challenges will require all citizens to have a better understanding of science and technology, if they are to participate actively and responsibly in science-informed decision-making and knowledge-based innovation (Hazelkorn *et al.*, 2015). As a consequence, increasing the interest of young people for science is a priority to improve society's appetite for innovation and open up further research and innovation activities.

In this context, the proposed activity showed a possible solution to successfully raise the interest of high-school students for chemical science in its various aspects, comprising analytical, inorganic, physical, organic, and industrial chemistry. It emphasized multidisciplinary aspects and focused on the interest aroused by the subject of scientific investigation of the crime scene and on the direct involvement of the student in all phases of the work, *i.e.* the realization of the experiments, the discussion of the results, possible explanations and implications, the presentation of the conclusions and the resolution of the case. Moreover, it was made apparent to them that a given scientific problem needs to be faced from different points of view and with high critical thinking, in order to come to a sound conclusion.

Specifically, data from a self-report questionnaire assessing interest and attitude toward chemistry, pleasure for the study of chemistry, beliefs about chemistry, self-efficacy in chemistry, and self-concept in chemistry showed that after the activity there was a general significant increase in interest and attitude. We also found that students who showed a significant change (increase) in this variable were those who had lower scores in pleasure for the study of chemistry and self-efficacy and self-concept in chemistry before the activity. Overall, the results of this study suggest that the activity can be especially effective on those students that show relatively lower levels of positive attitude and self-efficacy in chemistry. Future studies could investigate whether these students differ from their peers in other variables relevant to school achievement, such as motivation and/or learning styles. The playful and emotionally engaging context could have changed the students' motivation from poor and extrinsic to one based on incentives, the positive emotion being the reward for studying chemistry. A further step, after this activity, would be directed toward the development of an intrinsic motivation, where the pleasure for the study of chemistry is no longer dependent on the playful context, but is found in the subject itself.

The experiences have always been challenging and exciting, as demonstrated by the answers to the questionnaire filled in by the students at the end of the internship. A limitation of this result could be the use of self-report measures, which could have introduced some well-known potential biases of questionnaire measures, such as socially desirable and acquiescent responding. The anonymous completion of questionnaires should have controlled these biases, but a more conclusive test of the efficacy of the activity described here could be obtained by comparing objective chemistry achievement before and after the activity, as it would also shed light on its long-term effect.

Conflicts of interest

There are no conflicts to declare.

Appendix 1: statistical analysis results

Significant effects are reported in bold (Tables 3–6).

Table 3 Pleasure for the study of chemistry (Q8–10)

	Estimate	Std error	df	*t* value	Pr(>|*t*|)
Intercept	4.122	1.300	75.00	3.171	0.0022
Interest	−0.782	0.392	75.00	−1.994	**0.0498**
School type	1.073	0.396	75.00	2.709	**0.0084**
Gender	0.438	0.281	75.00	1.555	0.1242
Grade	−0.004	0.316	75.00	−0.013	0.9899

Note: significant effects are indicated in bold.

Table 4 Beliefs about chemistry (Q11–12)

	Estimate	Std error	df	*t* value	Pr(>|*t*|)
Intercept	2.933	0.979	76.00	2.995	0.0037
Interest	0.149	0.286	76.00	0.521	0.6042
School type	0.038	0.298	76.00	0.128	0.8985
Gender	0.093	0.212	76.00	0.441	0.6606
Grade	0.207	0.238	76.00	0.867	0.3889

Table 5 Self-efficacy in chemistry (Q13–17)

	Estimate	Std error	df	*t* value	Pr(>|*t*|)
Intercept	4.913	1.124	75.92	4.372	3.85×10^{-5}
Interest	−0.620	0.318	70.81	−1.949	**0.0553**
School type	0.464	0.329	68.04	1.412	0.1625
Gender	0.359	0.235	70.14	1.527	0.1313
Grade	−0.235	0.274	75.92	−0.858	0.3934

Note: significant effects are indicated in bold.

Table 6 Self-concept in chemistry (Q18–20)

	Estimate	Std error	df	*t* value	Pr(>|*t*|)
Intercept	5.047	0.803	75.96	6.284	1.9×10^{-8}
Interest	−0.505	0.228	70.52	−2.217	**0.0298**
School type	−0.012	0.236	67.40	−0.051	0.9593
Gender	0.056	0.168	69.72	0.334	0.7392
Grade	−0.075	0.196	75.97	−0.385	0.7015

Note: significant effects are indicated in bold.

Appendix 2: recruitment test

The recruitment test and instructions were delivered in Italian. The material was translated for this paper. Response options in bold type are the correct ones.

Question 1: how can you determine the date of death of a corpse found after several days?

(a) from the body temperature; **(b) by entomological analysis**; (c) from the rigidity of the body (*rigor mortis*).

Question 2: which chemical elements are searched for in the analysis of residues of gun powder?

(a) Sb–Pb–Ba; (b) Pb–Cu–Zn; (c) Pb–C–Ti.

Question 3: when can you say that two fingerprints match?

(a) when they are perfectly superposable; **(b) when they display a certain number of coincident** ''**unique regions**''; (c) when they have the same number of ''ridges'' and ''grooves''.

Question 4: on what kind of reaction are explosives generally based?

(a) combustion; (b) hydrolysis; **(c) self redox**.

Question 5: what pathological criterion indicates a strychnine poisoning?

(a) early stiffness; (b) carmine red hypostasis; (c) early putrefaction.

Question 6: what is the active ingredient of Ecstasy?

(a) lysergic acid diethylamide; **(b) 3,4-methylenedioxymethamphetamine**; (c) delta-9-tetrahydrocannabinol.

Question 7: which metallic element is present in the heme group of hemoglobin?

(a) Ca; **(b) Fe**; (c) Em.

Question 8: what is the difference between deflagration and detonation?

(a) in the detonation expansion is supersonic; (b) the explosion causes more extensive damage; (c) the detonation requires a trigger device.

Question 9: how samples are collected in the analysis of residues of gun powder?

(a) by means of adhesive pads; (b) on a photographic plate; (c) with micro-tweezers.

Question 10: bleach (sodium hypochlorite) is:

(a) an acid; **(b) an oxidant**; (c) a buffer.

Question 11: A girl drinks caustic soda, erroneously dissolved in mineral water. The acid caused her severe burns. Where is the mistake?

(a) caustic soda is not an acid; (b) caustic soda does not cause burns; (c) caustic soda cannot be dissolved in mineral water.

Question 12: which wine sophistication causes its high toxicity?

(a) addition of ethyl alcohol; **(b) addition of methanol**; (c) addition of sucrose.

Appendix 3: experimental details

Workplan

The activity, which lasts one week, involves 25 students, split into groups of 5. The workplan is as follows:

– Monday morning: presentation of the case study, assignment of participants to groups 1–5 and recruitment test.

– Monday afternoon: analysis of evidence with luminol and ninhydrin.

– Tuesday morning and afternoon, Wednesday morning: three distinct laboratory experiences.

– Wednesday afternoon: preliminary elaboration of data.

– Thursday morning and afternoon: two distinct laboratory experiences.

– Friday morning: final elaboration of data and preparation of the presentation.

– Friday afternoon: presentation and conclusion.

The case study

A girl is found murdered in a burned car. The autopsy revealed that the cause of death was a stab wound in the back. The car fire, possibly arson, occurred later, probably to conceal or eliminate evidence. In fact, very little evidence has been found in the car, which will be the subject of this investigation: (A) a butcher's knife, the supposed murder weapon; (B) white powder; (C) strip of cloth; (D) fragments of plaster; (E) cotton balls; (M) semi-burnt envelope; (N) metal tube. To them, a series of car interior parts (F1–F10) are added, together with (G) a fragment of blade found in the back of the victim, (H1–H5) strands of hair taken from the suspects, (I1–I5) pieces of cloth taken from clothing worn by the suspects the night of the murder, and (L) plaster dust retained on the mason's clothing.

The victim is Kassandra Scarlet, 25, an office secretary and artistic restoration aficionado. On the evening of the murder she left work in a hurry because of a severe toothache.

The suspects are:

(1) Jacob Green, 30, brother of the victim, a butcher, the sole heir of the family assets in the event of the death of his sister.

(2) Victor Plum, 28, partner of the victim, a mason, a weightlifting enthusiast, had a violent quarrel with the girl the night before the murder for reasons of jealousy.

(3) Diane White, 27, a friend of the victim, employed in a grocery store, ex-girlfriend of Victor Plum and envious of her beauty.

(4) Jack Mustard, 52, a neighbor, a worker in a steel industry, with a criminal record of stalking of the victim.

(5) Eleanor Peacock, 35, a colleague of the victim, had a heated argument a few days before the murder.

Evidence and deductions from the distinct laboratory experiences

Luminol test. The analysis of the butcher's knife (A) gives a positive result and is therefore sent to an external laboratory for DNA analysis. Moreover, following the analysis of a series of car interior parts, F2 and F3, which have given positive results, are sent for DNA analysis. On the last day the results of these analyses will be handed over to the students. A: no genetic material. F2 and F3: victim's DNA. The analyses are therefore inconclusive.

Ninhydrin test. The fingerprints found on the semi-burnt envelope (M) are sent to an external laboratory for identification. By comparison with the fingerprints of the suspects, compatibility with suspects 1-2-3 is found. However, the presence of fingerprints of 1-2-3 in the car of the victim is plausible and the analysis is inconclusive.

Analytical chemistry activity. Analysis of the white powder (B) allows recognizing it as magnesium, presumably found as residue from the improvised explosive device used to set the car on fire. Because those who have handled such substance could keep a record in the hair as surface contamination, strands of hair taken from the suspects (H1–H5) are analyzed quantitatively by finding that 1-5 have a ''natural'' level, while 2-3-4 have a significantly higher concentration. For suspect 2, this can be attributed to magnesite probably used in the gym; while for

Table 7 Summary scheme

Activity	Evidence	Suspected	Exonerated
Luminol test	A; F1–F10	—	—
Ninhydrin test	M	1-2-3	—
Analytical chemistry	B; H1–H5	2-3-4	1-5
Organic chemistry	E	3	—
Inorganic-metallurgical chemistry	A, G, N	4	1
Physical chemistry	D, L	—	2
Industrial chemistry	C; I1–I5	3-5	1-2-4

suspect 4, the working activity in the steel sector may explain the result. For suspect 3 there is no plausible explanation.

Organic chemistry activity. The analysis of the cotton balls (E) enables recognizing the identity of the essence of which they are impregnated with, on the basis of the main component (eugenol): it is the essence of clove, which could have been used by the victim to soothe toothaches and could also be connected with the work activity of suspect 3 (shop assistant in a grocery store).

Inorganic–metallurgic chemistry activity. The X-ray fluorescence analysis of the blade fragment (G) taken from the victim's back shows its incompatibility with the stainless steel butcher's knife (A), exonerating suspect 1. The fragment is in fact nickel-plated steel, similar to pipe material (N) found at the crime scene.

Physical chemistry activity. The analysis of the fragments of plaster (D) leads to the conclusion that it is not the plaster dust retained on the mason's clothes (L), but rather material used for artistic restoration (a passion of the victim).

Industrial chemistry activity. The analysis of the pieces of cloth (I1–I5) taken from the suspects and the comparison with the strip of cloth found at the crime scene (C) leads to the conclusion that the latter is compatible with clothing worn by suspects 3-5 on the night of the crime, while those of 1-2-4 consist of fibers of different natures (Table 7).

Detailed descriptions of each activity

The adopted procedures were not necessarily taken from official protocols, but were selected in order to be plausible, conceptually suitable for high school students and realizable in a three-hour activity. Moreover, the choice of the procedures was aimed to include all branches of chemistry, so that, in some case, not the standard procedure was selected. For example, the comparative analysis of hair samples by optical or electron microscopy is the normal procedure in forensic hair analysis, but the magnesium quantification in hair allowed us to introduce the quantitative analysis concept, which is essential in the analytical chemistry field. However, the scientific consistency of each experiment was always considered. In the cited example, the analysis of surface hair contamination as evidence in a murder case was based on a report by Pillay *et al.* (1973). In this case, the authors produced evidence of hair contamination, linking the criminal to a certain occupation. This link, along with certain corroborative evidence, was considered sufficient by the jury to decide in favor of the prosecutors.

Finally, several procedures made use of high-level instruments, which are not usually available in high schools. However, this should not be seen as a weakness but rather as a strong point of the proposed activity, which was designed to be carried out inside the University, in order to create a connection between educational institutions and allow students to get in contact with modern techniques and advanced methodological approaches.

Activity 1a – luminol test. The search for traces of hemoglobin is carried out by spraying, on cloth or other porous surfaces, in which the existence of traces of blood is suspected, a solution containing the reagent called luminol (5-amino-2,3-dihydrophthalazine-1,4-dione). In a strongly alkaline medium, in the presence of oxidants which contain the peroxide group (*i.e.* H_2O_2) and in the presence of a catalyst, luminol is oxidized to the corresponding phthalate. Cationic species such as Fe^{2+}, contained in the heme group of hemoglobin, can act as a catalyst for this reaction. The product of this reaction is formed in an excited state, and spontaneously relaxes back to the ground state by emission of a photon. This emission is responsible for the blue glow typical of a positive test. In the presence of stronger oxidants (such as bleach) the reaction can occur also in the absence of a catalyst.

The test solution is prepared as follows: in a 100 mL beaker weigh 1.5 g of KOH and 0.2 g of luminol, dissolve in 25 mL of deionized water, and then add 10 mL of hydrogen peroxide 3% solution. The test solution is used to analyze exhibits A and F1–F10. Exhibits A and F2 and F3 are preliminarily treated with bleach.

Activity 1b – ninhydrin test. Fingerprints can be highlighted with a reagent called ninhydrin. This reacts with the amino acid component of sweat, giving a purple color that makes the ridges visible. Ninhydrin (2,2-dihydroxy-1,3-dioxohydrindene) is a specific indicator for the detection of amino acids as it reacts with them developing an intense purple color; the reaction is fast, but sometimes it is necessary to speed it up by heating for a few minutes.

The ninhydrin solution is prepared as follows: in a 100 mL volumetric flask weigh 0.4 g of ninhydrin and dissolve it in 2 mL of methanol, then add 7 mL of ethyl acetate and 1 mL of acetic acid and make up to the volume with petroleum ether.

The semi-burnt envelope (preliminarily impressed with various fingerprints) is cut into pieces and dipped into the ninhydrin solution; then they are transferred into a stove at 90 °C for 10 minutes. The students select then the fragments containing fingerprints.

Activity 2 – analytical chemistry. A preliminary flame test with various metals is used to give a first clue on the nature of the unknown powder (exhibit B). Once the presence of magnesium has been suggested, a qualitative analysis is performed as follows: dissolve an aliquot of sample B in diluted HCl. Take 3 mL of 3 M NaOH solution and add up to complete precipitation. Measure the pH of the supernatant. Centrifuge and discard the solution. Dissolve the precipitate with 6 M HCl. Add 3–4 drops of azo violet II (4-(4-nitrophenylazo)-1-naphthol) 0.01% in 2N NaOH. Add NaOH drop by drop up to basic pH. A blue precipitate confirms the presence of magnesium.

The second part of this activity is focused on the quantitative analysis of exhibits H1–H5. Weigh precisely 20–50 mg of each sample and put them into 5 flasks. Under a fume hood, add 20 mL of HNO_3 1 : 1 (v/v) and heat it to the boiling point on a hot plate. Transfer the solutions into 50 mL volumetric flasks and make up to the volume with deionized water. Prepare a series of standard magnesium solutions by diluting a stock Mg solution 1000 ppm. Analyze the standards and samples using atomic absorption spectrometry (samples 2-3-4 have to be furtively spiked with a magnesium standard solution to obtain a high concentration).

Activity 3 – organic chemistry. The essential oil of cloves is recovered by cotton balls through steam distillation; the resulting emulsion is extracted with ethyl acetate and the organic solution is analyzed by means of gas chromatography-mass spectrometry (GC-MS) to identify the single component of the mixture.

Steam distillation: place the cotton ball in a 100 mL round bottom flask, add 60 mL of distilled water and build the distillation apparatus. Heat it until boiling and distill it into test tubes until the distillate is clear, indicating that there is no essential oil left on the cotton ball.

Liquid–liquid extraction: transfer the test tubes containing the essential oil (opalescent solution) into a separatory funnel, add ethyl acetate (20 mL) and separate the phases. Collect the organic phase and re-extract the water phase with ethyl acetate (20 mL). The combined organics are anhydrified and concentrated under reduced pressure. The resulting oil is used for qualitative analysis.

GC-MS analysis: weigh 1 mg of the resulting oil in a vial and dissolve it in 1 mL of diethyl ether. Perform gas chromatographic analysis with an instrument coupled with a mass spectrometer. Observe the peaks on the chromatogram and identify the corresponding substances through their fragmentation pattern, with the aid of a database.

Activity 4 – inorganic/metallurgical chemistry. Exhibits A and N are analyzed using a portable X-ray fluorescence instrument that allows highlighting the differences between a stainless steel and a chrome-plated steel.

Metallographic samples of exhibits A and G are prepared by incorporation into resin, then polished and observed under an optical microscope. Subsequent metallographic attack of the surface put in evidence the crystal structure. Thanks to scanning electron microscopy equipped with an elemental X-ray microanalyzer, it is possible to observe the true nature of the two exhibits, and recognize the fragment found in the back of the victim as a chrome-plated steel and not a stainless steel.

Activity 5 – physical chemistry. The carbonate component of plaster, stone materials and products for restoration are subjected to acid treatment. Upon dissolution, the residue is analyzed and evaluated. This preliminary experiment is aimed at explaining that there are products on the market which, due to their characteristics and their cost, are only used for consolidation of surfaces with high historical and artistic value and not in normal construction sites.

Exhibits D and L are then analyzed by X-ray diffraction of powders. By comparison between the spectra obtained from the two samples, the different compositions and crystal structures are highlighted.

Activity 6 – industrial chemistry. Natural and synthetic polymers have distinct chemical reactivities. Simple experiments can be performed to determine the structure of the polymer and therefore the nature of the fabric.

Microscopic analysis: separation of warp and weft fibers is followed by their deposition on a microscopy glass slide, by dipping them in one drop of paraffin. Observation and image recording are performed.

Proof of combustion: bring the fibers (warp and weft separately) to the open flame and observe how the combustion proceeds, the aspect of the unburned residue and the smell released during combustion.

Dry distillation: insert the fibers (warp and weft separately) in test tubes and place a piece of moistened litmus paper on them, place the tubes on the open flame until the fibers start to melt and release vapors. Observe the color variation of the paper and determine the pH of the vapors.

Treatment with solvents: introduce a predefined amount (about 30 mg) of fibers (warp and weft separately) in a test tube and perform the following operations in succession:

(1) add 3 mL of acetone, heat to boiling for 5 min and note the results;

(2) if the fabric does not dissolve, remove the acetone with a pipette, add 3 mL of glacial acetic acid, heat to boiling for 2–3 minutes, and note the results;

(3) if the fabric does not dissolve, remove the acetic acid using a pipette, add 3 mL of nitrobenzene and note the results;

(4) if the fabric does not dissolve, remove the nitrobenzene with a pipette, add 3 mL of 10% KOH and note the results;

(5) if the tissue dissolves, add HCl at room temperature and note the results;

(6) if the fabric does not solubilize, take note of the result.

Further experimental details are available on request by the authors.

Acknowledgements

This project was financially supported by the Italian National Project ''Scientific Degrees Plan'' (MIUR).

References

Aikenhead G. S., (2005), Research into STS science education, *Educ. Quím.*, **16**, 384–397.

American Psychological Association, (2010), *Ethical principles of psychologists and code of conduct*, http://www.apa.org/ethics/code/index.aspx, last access: 20 February 2018.

Bennett J., Lubben F. and Hogarth S., (2007), Bringing Science to Life: A Synthesis of the Research Evidence on the Effects of Context-Based and STS Approaches to Science Teaching, *Sci. Educ.*, **91**, 347–370.

Beussman D. J., (2007), The mysterious death: an HPLC lab experiment. *J. Chem. Educ.*, **84**, 1809–1812.

Camodeca M., Di Michele C., Mela M. and Cioffi R., (2010), Adattamento italiano del Self-Description Questionnaire per bambini di età scolare e pre-adolescenti, *Giornale Italiano di Psicologia*, **37**, 673–694.

Dillon J. and Osborne J., (2008), *Science Education in Europe: Critical Reflections*, Report to the Nuffield Foundation, www.nuffieldfoundation.org/sites/default/files/Sci_Ed_in_Europe_Report_Final.pdf, last access: 27 October 2017.

Forsthuber B., Motiejunaite A., de Almeida Coutinho A. S., Baïdak N. and Horvath A., (2011), *Science Education in Europe: National Policies, Practices and Research*, Report to the European Commission by the Education, Audiovisual and Culture Executive Agency (EACEA P9 Eurydice), http://eacea.ec.europa.eu/education/eurydice/documents/thematic_reports/133en.pdf, last access: 27 October 2017.

Gago J. M., Ziman J., Caro P., Constantinou C. P., Davies G., Parchmannn I., Rannikmäe M. and Sjøberg S., (2015), *Europe needs more scientists!* Report to the European Commission by the high level group on increasing human resources for science and technology in Europe, https://www.researchgate.net/publication/259705752_Europe_Needs_More_Scientists_Report_by_the_High_Level_Group_on_Increasing_Human_Resources_for_Science_and_Technology, last access: 27 October 2017.

Gutwill-Wise J. P., (2001), The impact of active and context-based learning in introductory chemistry courses: An early evaluation of the modular approach, *J. Chem. Educ.*, **78**, 684–690.

Hasan S., Bromfield-Lee D., Oliver-Hoyo M. T., and Cintron-Maldonado J. A., (2008), Using laboratory chemicals to imitate illicit drugs in a forensic chemistry activity, *J. Chem. Educ.*, **85**, 813–816.

Hazelkorn E., Ryan C., Beernaert Y., Constantinou C. P., Deca L., Grangeat M., Karikorpi M., Lazoudis A., Casulleras R. S., Pintó R. and Welzel-Breuer M., (2015), *Science education for responsible citizenship*, Report to the European Commission by the expert group on science education, http://ec.europa.eu/research/swafs/pdf/pub_science_education/KI-NA-26-893-EN-N.pdf, last access: 27 October 2017.

Henck C. and Nally L., (2007), GC-MS analysis of gamma-hydroxybutyric acid analogs, *J. Chem. Educ.*, **84**, 1813–1815.

Henderleiter J. and Pringle D. L., (1999), Effects of context-based laboratory experiments on attitudes of analytical chemistry students, *J. Chem. Educ.*, **76**, 100–106.

Hidi S. and Renninger K. A., (2006), The four-phase model of interest development, *Educ. Psychol.*, **41**, 111–127.

Irwin A. R., (2000), Historical Case Studies: Teaching the Nature of Science in Context. *Sci. Educ.*, **84**, 5–26.

Jacobson N. S. and Truax P., (1991), Clinical significance: a statistical approach to defining meaningful change in psychotherapy research, *J. Consult. Clin. Psychol.*, **59**, 12–19.

Jøberg S. and Schreiner C., (2010), *The ROSE project: an overview and key findings*, Report to the European Commission, http://www.cemf.ca/%5C/PDFs/SjobergSchreinerOverview2010.pdf, last access: 27 October 2017.

Linnenbrink-Garcia L., Durik A. M., Conley A. M., Barron K. E., Tauer J. M., Karabenick S. A. and Harackiewicz J. M., (2010), Measuring situational interest in academic domains, *Educ. Psychol. Meas.*, **70**, 647–671.

Lubben F., Bennett J., Hogarth S. and Robinson A., (2005), The effects of context-based and Science-Technology-Society (STS) approaches in the teaching of secondary science on boys and girls, and on lower-ability pupils, in *Research Evidence in Education Library*, London: EPPI-Centre, Social Science Research Unit, Institute of Education, University of London, http://eppi.ioe.ac.uk/cms/Default.aspx?tabid=329, last access: 27 October 2017.

Marsh H. W., (1990), *Self-Description Questionnaire – II manual*, Sydney: University of Western Sydney.

McOwan P., Carpineti M., Giliberti M., Eilks I., Childs P., Hayes S., Jordan J., Sherborne T., Nyberg J., Lembens A., Mamlok-Naaman R., Russo P., Ctrnactova H., Olivotto C., Merzagora M. and Correia S., (2016), *Teaching Enquiry with Mysteries Incorporated*, Final Report Summary, http://cordis.europa.eu/result/rcn/192675_en.html, last access: 27 October 2017.

O'Dwyer A. and Childs P., (2014), Organic chemistry in action! Developing an intervention program for introductory organic chemistry to improve learners' understanding, interest, and attitudes, *J. Chem. Educ.*, **91**, 987–993.

OECD, (2015), *PISA 2015 database*, http://www.oecd.org/pisa/data/2015database/, last access: 21 March 2017.

Osborne J., Simon S. and Collins S., (2003), Attitudes towards science: a review of the literature and its implications, *Int. J. Sci. Educ.*, **25**, 1049–1079.

Palmer P. T., (2011), Energy-Dispersive X-ray Fluorescence Spectrometry: a long overdue addition to the chemistry curriculum, *J. Chem. Educ.*, **88**, 868–872.

Pernaa J. and Aksela M., (2011), Learning organic chemistry through a study of semiochemicals, *J. Chem. Educ.*, **88**, 1644–1647.

Pillay K. K. S., Thomas C. C. and Mahoney G. F. (1973), Examination of evidence materials for environmental contamination using activation analysis, *J. Radioanal. Chem.*, **15**, 33–39.

Randall D. W., Hayes R. T. and Wong P. A., (2013), A simple Laser Induced Breakdown Spectroscopy (LIBS) system for use at multiple levels in the undergraduate chemistry curriculum, *J. Chem. Educ.*, **90**, 456–462.

Ravgiala R. R., Weisburd S., Sleeper R., Martinez A., Rozkiewicz D., Whitesides G. M. and Hollar K. A., (2014), Using paper-based diagnostics with high school students to model forensic investigation and colorimetric analysis, *J. Chem. Educ.*, **91**, 107–111.

Saccocio L. A. and Carroll M. K., (2006), Density determination by water displacement and flotation: an introductory experiment in forensic chemistry, *J. Chem. Educ.*, **83**, 1187–1189.

Schiefele, U., (1991), Interest, learning, and motivation, *Educ. Psychol.*, **26**, 299–323.

Sjøberg S., (2002), Science and Technology Education in Europe: Current Challenges and Possible Solutions, *UNESCO International Science, Technology & Environmental Education Newsletter*, vol. XXVII, http://unesdoc.unesco.org/images/0014/001463/146315e.pdf, last access: 27 October 2017.

Taber K. S., (2014), Ethical considerations of chemistry education research involving 'human subjects', *Chem. Educ. Res. Pract.*, **15**, 109–113.

Wigfield A. and Eccles J. S., (2000), Expectancy-value theory of achievement motivation, *Contemp. Educ. Psychol.*, **25**, 68–81.