INSTRUCTIONAL DESIGN AND ASSESSMENT

Using Problem-Based Learning in a Chemistry Practical Class for Pharmacy Students and Engaging Them with Feedback

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Objective. To introduce a new approach to problem-based learning (PBL) used in a medicinal chemistry practical class for pharmacy students.

Design. The chemistry practical class was based on independent studies by small groups of undergraduate students (4-5), who designed their own practical work, taking relevant professional standards into account. Students were guided by feedback and acquired a set of skills important for health-care professionals. The model was tailored to the application of PBL in a chemistry practical class setting for a large student cohort (150 students). The achievement of learning outcomes was based on the submission of relevant documentation, including a certificate of analysis, in addition to peer assessment. Some of the learning outcomes also were assessed in the final written examination.

Assessment. The practical was assessed at several time points using detailed marking schemes in order to provide the students with feedback. Students were required to engage with the feedback to succeed in the practical.

Conclusion. A novel PBL chemistry laboratory course for pharmacy students was successful in that self-reflective learning and engagement with feedback were encouraged, and students enjoyed the challenging learning experience. Essential skills for health-care professionals were also promoted.

Keywords: problem-based learning, medicinal chemistry laboratory class, virtual client, quality assurance, feedback.

INTRODUCTION

Problem-based learning initially was developed in medical schools as a format for self-directed learning and to acquire problem-solving skills.¹⁻⁶ It significantly differs from other learning approaches, where students are equipped with knowledge prior to the exercise.⁷ A mentor provides guidance, monitoring, and feedback to a group of 5-6 students and plays a crucial role within this learning environment.⁸

Schools of pharmacy around the world, including in the United States, Canada, and Europe, increasingly use a PBL-approach for instruction because problem-solving, critical-thinking, and decision-making skills are crucial for pharmacists.⁹⁻¹¹ Problem-based learning often is limited to clinical pharmacy or pharmacology teaching, although some approaches use PBL as an interactive tool within a series of medicinal chemistry lectures.¹²

There are limited examples of a PBL approach being used to teach a large-size chemistry or science practical

class at the university level. Examples include using “PBL mini projects” instead of the traditional “prefabricated” chemistry laboratory practical.¹³ Health and safety concerns, staff numbers, and the logistics of managing large class sizes in a laboratory environment with minimal instruction can be limiting factors.

In this paper, we report on the design of a novel medicinal chemistry-based practical class that uses PBL. Problem-based learning is the teaching medium for a number of modules at the University of Reading School of Pharmacy, but this is the first medicinal chemistry laboratory class to use it. The design addresses typical issues found in PBL approaches, such as high staffing needs and the time-consuming aspect of feedback.

DESIGN

The medicinal chemistry module focuses on the use of metal-based drugs in a variety of therapeutic areas. The module hosts up to 150 students and contains traditional lectures, workshops, tutorials, and practical classes. Students are introduced to a variety of elements, a range of inorganic compounds, and the clinical uses of these substances. Students are expected to integrate therapeutic knowledge acquired in Part 1, 2, and 3 with medicinal

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and analytical chemistry. Part of this module is an 8-hour practical class, which focuses on the quality control of these drugs.

The laboratory classes are designed for 150 students, but still provide the students with the experience of small-group learning. Students typically work in groups of 4-5. The main teaching process is led by 1-2 academic staff facilitators. The groups are also supported by PhD student mentors. Typically, there are 4-6 mentors for the whole cohort, and their main duty is to supervise the laboratory work and to support the student groups in their experimental design and data analysis.

The aim of the practical class is for students to achieve the following learning objectives: research and understand the literature regarding relevant quality assurance procedures; engage with quality assurance protocols and regulations; devise an experimental setup; undertake health and safety risk assessments; perform chemical analysis to a high standard; practice scientific calculations; develop and strengthen understanding of unit conversion and technical limitations; evaluate results in relation to relevant standards; and present outcomes to virtual clients. The practical experiment is one of many elements assessed in this practical class. Emphasis is placed on the process of literature research, in addition to testing understanding of and implementing this information.

Previously, practical classes were designed using a traditional approach. Students were provided with a practical manuscript containing information about the experimental setup and background information, along with health and safety information. An element of interactive learning was to provide students with an online health and safety test. Student engagement with the learning objectives was limited, and the students acted more like consumers rather than active learners. Nevertheless, they still obtained high marks (grades) for the practical element, though this performance was not replicated in the written examination.

Therefore, we decided to design a novel practical class, where students would engage with learning objectives and where a spread of grades, commensurate with a range of abilities, would be achieved. The redesign of the class was supported by the Pharmacy Board of Teaching and Learning, and the analysis of the subsequent outcomes approved by the school's research ethics committee.

The new PBL chemistry practical class provided students with limited health and safety information and no laboratory manual. The class was divided into groups of 4-5 students. Each group was asked to start their own virtual pharmaceutical company, and they were provided with some dedicated laboratory space containing

equipment and chemicals. The groups received a short brief from their virtual client, stating their task. This brief varied according to the lecture material, and it could be tailored to the individual module outcomes.

A typical task was to analyze an active pharmaceutical ingredient (API) in a batch of newly manufactured drugs. The virtual client would ask, for example, if the API quantity was within legally acceptable limits so the manufactured drugs could be released to the market. Other options included identification of the API or the physical testing of the formulation. No further instruction was given. Each virtual company was given a series of forms for communication with the virtual client. This led students through the learning process but did not interfere with the PBL approach.

The choice of the drug determined what experimental elements were practiced in the laboratory. The quantitative analysis of most metal-based drugs was undertaken by a series of titrations. Thus, the preparation of the required standard solutions was a crucial step, as was determining their exact concentrations. Other drugs required UV-Vis analysis, high-performance liquid chromatography (HPLC), potentiometry, etc. Using a drug containing a mixture of APIs, the students also were required to separate individual compounds. Therefore, the complexity of the task could be tailored by the choice of drug.

Typical instruments used included UV-Vis spectrometers, HPLC, or titration glassware. The practical setup varied according to the chosen drug and, therefore, could be tailored to laboratory equipment. Analytical instruction in the pharmacopoeia could typically be undertaken with relatively "simple" equipment. Typically, each group was provided with a different batch of drugs, which meant the API, the formulation, or the strength varied. An example of a practical write-up showing the quantitative analysis of ferrous sulphate is provided in Appendix 1.

Students went through predetermined steps within the PBL scenario as a result of the setup. Within the first 3 weeks students focussed on the Chemistry of the API, and researching the literature for the legal requirements. These are typically the legally binding country-specific pharmacopoeia. Students will have learned how to use these in previous modules. Furthermore, they were required to design their experimental setup and undertake their health and safety assessment. The outcome was their communication with their virtual client about the proposed experimental setup in order to obtain approval. Weeks 4-6 were dedicated to undertaking the quantitative analysis of the API content in their drug. The analytical skills required are taught to students in previous years. Typically, the analysis was based on simple titration,

HPLC or UV-Vis analysis. Additionally, the students were required to evaluate their results according to the relevant professional standards and present them to their virtual client. All students had to create a certificate of analysis.

In line with the PBL ethos, each group had access to a mentor, who guided them through initial research, experiments, and evaluation of their results. Group feedback was given to the students on a regular basis either orally from mentors, or more importantly, through written formative feedback via written communication with their virtual clients (written by the facilitator).

The assessment, based on the range of learning, was complex. Students were assessed as a group on a variety of criteria outlined in the marking scheme (Appendix 2). The groups received grades for experimental design, research of the scientific background, health and safety assessment, practical performance, evaluation of their results, and presentation to the virtual client. In addition, students were invited to use peer assessment, which allowed the lead academic of the practical class to assess individual contributions to the work. Some of the learning outcomes are assessed in the end-of-year written examination.

The PBL practice built on students' prior knowledge of quality control, health and safety assessments, and standard analytical tests obtained from previous lectures and practical classes. Basic knowledge from these previous modules, together with newly acquired information, was applied to the PBL scenario. The students built on their basic knowledge and engaged in self-directed studies to achieve the learning outcomes. Examples for the drug analyses were chosen according to the level of students' experience.

The practical class was also designed to prepare students for their research project in the final year as the students were introduced to independent research work. The laboratory work was only a small part of the PBL scenario, which placed more emphasis on the whole process and accuracy of such work. The students were, for example, required to find the correct legally binding procedures and to think about accuracy and standardization on a level appropriate for work in a pharmaceutical quality assurance laboratory. All of these skills are important for a successful final year research project.

EVALUATION AND ASSESSMENT

The practical element contributed a total of 20% toward the final module grade at the time of the PBL design. Within the previous traditional practical class, the assessment had been based on the practical work and on report writing, where the latter contributed significantly more to the final grade. Students achieved high marks for the

coursework, with averages of 68.6%, 77.3%, 65.2% and 80.7% in previous years.

In addition to the high average grades, there was a poor spread of practical grades as seen in Table 1. In most years, more than half of the cohort received a grade of 70% or better for their coursework. The high coursework grades certainly were not mirrored by excellent performance on the end-of-year written examination. Typically, the examination grade was around 45%, with little variation between cohorts.

We designed the new PBL practical to address these issues, and it appeared to fulfill our expectations, such as engaging students with feedback and integration of knowledge. The average coursework grade was 65.4% in 2013-2014, and the individual grades showed a better spread (Table 1) and followed the typical Gaussian distribution as expected. Also the average examination grade increased significantly to 65% and was in line with the practical grade.

Students actively participated in this practical class based on student feedback comments we received and on high attendance rate (98%). All feedback sessions provided during the PBL process were well-attended, and students came prepared to address the previous feedback comments. It became clear in the module evaluation that the practical was perceived as challenging but also as a useful teaching tool.

The design directed students to fully understand the different steps of the practical, such as literature research, health and safety protocols, experimental process, and calculations. A lack of engagement at any stage would have resulted in an incomplete report submission. In turn, students who struggled in the initial steps were still able to pick up good grades if they engaged at a later stage as a result of responding to feedback.

DISCUSSION

The new practical class was designed to engage students and mirror real-life working situations. It was important to choose relevant real-life scenarios to motivate students, and students engaged well with this practical. Attendance at the practical classes was 98%, despite no grade allocation for attendance. All student groups submitted their report on time; late submission would have resulted in a penalty, according to standard university policy. To evaluate the new problem-based learning model described, students had the opportunity to complete a feedback form at the end of the course, and we had a return rate of 76%.

In general, students found the practical class interesting but also challenging and relevant to their future professional career. Negative comments on the initial

Table 1. Grade Distribution in the Traditional-Style Practical: Spread of Coursework Grades Visualized in % Students per Degree Classification

	% Student per Degree Classification				
	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014
70-100%	55.6	72.0	44.6	93.8	26.4
60-69.9%	25.6	21.5	22.9	3.8	41.9
50-59.9%	13.3	5.6	15.7	0.0	24.0
40-49.9%	4.4	0.0	12.0	0.0	6.2
Failed	1.1	0.9	4.8	2.5	1.6

offering concerned the weighting of coursework to module grade as students felt that the coursework had become more work intensive. This was addressed for subsequent student cohorts by adjusting the weighting of examination to coursework within the module.

Evaluation of the coursework grades showed the majority of students achieved between 60% and 69.9%. The general grade distribution followed the typical Gaussian distribution. This overcame one of the problems of the previous practical design.

The facilitator, leading the teaching experience, and mentor, supporting the teaching experience, play an important role in any PBL scenario. Within this PBL practical class, each group was allocated a mentor, who supported the group during experimental design, throughout the laboratory work, and for the final submission of reports to the virtual client. We observed that mentors played an invaluable role in guiding the work, without significantly influencing the students' work. Communicating with their peers and mentors allowed students to practice their communication skills. Group work, especially organizing this challenging practical, also prepares students for real-life scenarios, where working as part of a team (eg, multi-disciplinary health-care teams) would be essential. Additionally, the PBL approach encouraged logical thinking, which promotes problem-solving skills.

Potential health and safety concerns about allowing a large cohort (150 students) into a laboratory without a strict instruction manual were addressed. The experimental design had to be submitted for approval before the laboratory work could take place. The design of the experimental setup also was restricted; students only had access to a limited variety of chemicals and equipment to minimize risk.

The workload for academic staff members who facilitated the course did not significantly increase, compared with a typical medicinal chemistry practical. Leading this practical for 150 students required 1-2 academic staff members supported by 4-6 mentors, in addition to the technical staff, which is typical for a chemistry practical class of this size.

Nevertheless, the timing of grading and feedback provision was shifted to occur alongside the PBL process. Within a traditional chemistry practical, marking and feedback takes place after the learning process. Often, feedback is significantly delayed because of the large class sizes, which in return minimizes the opportunities to meet learning outcomes for the students. This novel practical design required that the majority of grading be completed before students went into the laboratory. In turn, the grading and written feedback after the practical classes was significantly reduced. The workload distribution for the academic staff was rather unusual for a practical class, but expected for a PBL approach.

It is crucial for students to engage with feedback to progress within this practical as there are no written instruction manuals. If the students do not fully engage with the feedback, the practical class becomes more challenging. This relationship between provided feedback and the students engaging with feedback is an important aspect of the practical session, as other studies report that students request feedback, but are not able to act on the feedback given.¹⁴⁻¹⁶

Assessment of a PBL scenario is always a point for discussion, and this was no different for this practical class. Student groups received feedback and grades for researching and understanding the literature and designing the experimental setup. They were also evaluated on their health and safety assessment, their practical performance, evaluation of their results, and their presentation to their client. To facilitate such a complex assessment and feedback for a cohort of 150 students, we developed a grading scheme that took all the grading criteria into account and contained a short comment box for each criterion. These comments were given to students during the process and grades were only released as one final grade at the end of the practical to engage students with the feedback and not the grade itself. Student learning efforts often are centered on grades and not the feedback given.¹⁷

A potential weakness of this PBL practical compared to a traditional practical class is that students were exposed to a less varied hands-on experience. A significant

proportion of the time was spent on research and working with the scenario. In comparison, in a traditional laboratory class, the students spend most of their time performing 3-4 experiments. Problem-based learning is a more time-consuming learning process.¹⁸ Furthermore, the learning outcomes for a PBL laboratory class differ significantly from those of a traditional experimental class and are much more diverse.

From a teaching perspective, this practical class design can integrate knowledge and experiences from a variety of modules. The concept of curricular integration is emerging in modern education, and it is required for the university training of future pharmacists.¹⁹ Professional and regulatory bodies around the world demand an integrated teaching approach to equip the health care professional with the competencies to deal with a myriad of medical conditions in a large and complex health care system while not forgetting the needs of the patient.^{20,21}

CONCLUSION

The successful design of a PBL-based medicinal chemistry laboratory class allowed students to engage in real-life scenarios and interact with a virtual client. This laboratory class enabled the students to apply procedures relevant to quality control in the pharmaceutical industry by integrating a variety of knowledge acquired prior to the session. The PBL approach encouraged students to actively approach a variety of learning outcomes. Rather than a learning facts passively, students had to engage in self-directed learning and the feedback provided, and apply the information learned. The PBL-based practical class ensured that the learning process and feedback provision were aligned to maximize student experience. The detailed grading scheme made the feedback provision easy and effective, which may enable this practical design to be used for large class sizes.

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Appendix 1. Practical form illustrating the quantitative analysis of ferrous sulfate. Students are given the empty form with minimal instructions as a guidance for their work and a way of communication with their virtual client.

COMPANY NAME: University of Reading, School of Pharmacy

TASK: Analysis of quantity of Fe^{2+} in Ferrous Sulphate Tablets [Ferrous Sulphate tablets, Actavis (65 mg Fe)]

EXPERIMENT:

I. Preparation and standardisation of 0.1 M sodium thiosulphate

Chemicals:

1. Sodium thiosulphate, 5 g
2. Sodium carbonate, 0.1 g
3. Potassium bromate, 0.0167 M, 20 ml x 3 (standard solution)
4. Potassium iodide solution, 16.6% w/v, 10 ml x 3
5. Hydrochloric acid, 7 M, 5 ml x 3
6. Starch solution, 1% w/v, 1 ml x 3

Dissolve 5 g of sodium thiosulphate and 0.1 g of sodium carbonate in sufficient deionised water to produce 200 ml.

Ascertain its exact concentration in the following manner. To 20 ml aliquot of 0.0167 M potassium bromate, add 40 ml of water, 10 ml of 16.6% w/v potassium iodide solution and 5 ml of 7 M hydrochloric acid. Titrate with the sodium thiosulphate solution using 1 ml of starch solution as indicator, added towards the end of the titration.

II. Preparation and standardisation of 0.1 M ammonium cerium (IV) sulphate

Chemicals:

1. Ammonium cerium (IV) sulphate, powder, 13 g
2. Sulphuric acid, 1 M, 100 ml
3. Potassium iodide, 2 g x 3
4. Sodium thiosulphate, 0.1 M (standard solution)
5. Starch solution, 1% w/v, 1 ml x 3

Dissolve 13 g of ammonium cerium (IV) sulphate in a 100 ml of 1 M sulphuric acid. Allow to cool and dilute to 200 ml with water.

Ascertain its exact concentration in the following manner. To 25 ml aliquot of the solution, add 2 g of potassium iodide and 150 ml of water. Titrate immediately with 0.1 M sodium thiosulphate using 1 ml of starch solution as indicator, added towards the end of the titration.

III. Determination of iron in ferrous sulphate tablets

Chemicals:

1. Tablets containing ferrous sulphate, 10
2. Sulphuric acid, 1 M, 20 ml x 3
3. Ferroin solution, 0.1 ml x 3
4. Ammonium cerium (IV) sulphate, 0.1 M (standard solution)

Weigh and grind to a fine powder 10 tablets. Dissolve a quantity of the powder containing 0.3 g of dried ferrous sulphate as completely as possible in a mixture of 30 ml of water and 20 ml of 1 M sulphuric acid, gently heat to facilitate dissolving if necessary. Cool and titrate with 0.1 M ammonium cerium (IV) sulphate using 0.1 ml of ferroin solution as indicator.

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4. Volumetric reagents and solutions/ Zinc Chloride, British Pharmacopoeia 2005, Volume IV, Appendix I B, p. A129
5. Complexometric Titrations/ Zinc Chloride, British Pharmacopoeia 2005, Volume IV, Appendix VIII D, p. A 225

Background: (describe here the background to your experiment; include a rationale for the chosen method and relevant references)

UNDERGRADUATE RISK ASSESSMENT

Experiment: Assay - Content of Iron in ferrous sulphate tablets, Course: PM3DS3

Student Name, Supervisor Name, Date

Highest Risk Code: Medium

Outline of experimental procedure: Oxidation-Reduction titration

Substance	Quantity	Hazard description	COSHH Risk code
Sodium thiosulphate, powder	5 g	Non - hazardous	Low
Sodium carbonate, powder	≤ 1 g	Irritant	Low
Potassium bromate, 0.0167 M	60 ml	Harmful, Toxic	Medium
Potassium iodide solution, 16.6% w/v	30 ml	Not a hazardous substance	Low
Hydrochloric acid, 7 M	15 ml	Corrosive, Irritant	Medium
Starch solution, 1% w/v	6 ml	Not a hazardous substance	Low
Ammonium cerium (IV) sulphate, powder	13 g	Irritant	Medium
Sulphuric acid, 1M	220 ml	Corrosive	Medium
Ferriin solution	0.6 ml	Dangerous for the environment	Low
Potassium iodide, powder	6 g	Irritant	Medium
Ferrous sulphate tablets	10	Irritant	Low

Precautions and control measures: Gloves, Laboratory Coat, Chemical Fume Hood, Safety Glasses

Waste Disposal: All aqueous solutions should be disposed in the aqueous base waste container; all solid waste should be discarded into solid waste container in the fume hood

ANALYSIS - Data:

I. Preparation and standardisation of 0.1 M sodium thiosulphate

Volume of Na₂S₂O₃:

1. Titration: _____ ml

2. Titration: _____ ml

3. Titration: _____ ml

Average: _____ ml

II. Preparation and standardisation of 0.1 M ammonium cerium (IV) sulphate

Volume of Na₂S₂O₃:

1. Titration: _____ ml

2. Titration: _____ ml

3. Titration: _____ ml

Average: _____ ml

III. Determination of iron in ferrous sulphate tablets

Number of tablets: _____

Total mass of tablets: _____ g

Average mass of a single tablet: _____ g

Mass of a sample powder used: _____ g

Volume of (NH₄)₄Ce(SO₄)₄:

1. Titration: _____ ml

2. Titration: _____ ml

3. Titration: _____ ml

Average: _____ ml

ANALYSIS – Results:

I. Preparation and standardisation of 0.1 M sodium thiosulphate

Equation 1: $\text{KBrO}_3 + 6\text{KI} + 6\text{HCl} = 6\text{KCl} + \text{KBr} + 3\text{I}_2 + 3\text{H}_2\text{O}$; $\text{BrO}_3^- + 6\text{I}^- + 6\text{H}^+ = 3\text{I}_2 + 3\text{H}_2\text{O}$

Equation 2: $2\text{Na}_2\text{S}_2\text{O}_3 + \text{I}_2 = \text{Na}_2\text{S}_4\text{O}_6 + 2\text{NaI}$; $2\text{S}_2\text{O}_3^{2-} + \text{I}_2 = \text{S}_4\text{O}_6^{2-} + 2\text{I}^-$

1. The number of moles of KBrO₃ used: $n(\text{KBrO}_3) = C(\text{KBrO}_3) \times V(\text{KBrO}_3)$

2. From the stoichiometry of the reaction, the number of moles of sodium thiosulphate reacted: $\text{KBrO}_3 \equiv 3\text{I}_2 \equiv 3 \times 2\text{Na}_2\text{S}_2\text{O}_3 \equiv 6 \text{Equivalent}$; $n(\text{Na}_2\text{S}_2\text{O}_3) = n(\text{KBrO}_3) \times 6$

3. The concentration of the sodium thiosulphate: $C(\text{Na}_2\text{S}_2\text{O}_3) = n(\text{Na}_2\text{S}_2\text{O}_3) / V(\text{Na}_2\text{S}_2\text{O}_3)$

II. Preparation and standardisation of 0.1 M ammonium cerium (IV) sulphate

Equation 1: $2\text{Ce}^{4+} + 2\text{I}^- = \text{I}_2 + 2\text{Ce}^{3+}$

Equation 2: $2S_2O_3^{2-} + I_2 = S_4O_6^{2-} + 2I^-$

1. The number of moles of the titrant used: $n(Na_2S_2O_3) = C(Na_2S_2O_3) \times V(N_2S_2O_3)$
2. From the stoichiometry of the reaction, number of moles of ammonium cerium (IV) sulphate reacted: $2(NH_4)_4Ce(SO_4)_4 \equiv I_2 \equiv 2Na_2S_2O_3 \equiv 1 \text{ Equivalent}$; $n((NH_4)_4Ce(SO_4)_4) = n(N_2S_2O_3)$
3. The concentration of the ammonium cerium (IV) sulphate: $C((NH_4)_4Ce(SO_4)_4) = n((NH_4)_4Ce(SO_4)_4) / V((NH_4)_4Ce(SO_4)_4)$

ANALYSIS – Results: (continuing)

III Determination of iron in ferrous sulphate tablets

$2FeSO_4 + 2(NH_4)_4Ce(SO_4)_4 = Fe_2(SO_4)_3 + Ce_2(SO_4)_3 + 4(NH_4)_2SO_4$; $Fe^{2+} + Ce^{4+} = Fe^{3+} + Ce^{3+}$

1. The number of moles of the titrant used: $n((NH_4)_4Ce(SO_4)_4) = C((NH_4)_4Ce(SO_4)_4) \times V((NH_4)_4Ce(SO_4)_4)$
2. From the stoichiometry of the reaction, the number of moles of ammonium cerium (IV) sulphate reacted: $2(NH_4)_4Ce(SO_4)_4 \equiv 2FeSO_4 \equiv 1 \text{ Equivalent}$; $n((NH_4)_4Ce(SO_4)_4) = n(FeSO_4)$
3. The mass of calcium carbonate in the sample powder used: $m(FeSO_4) = n(FeSO_4) \times Mw(FeSO_4 \cdot xH_2O)$

The mass of ferrous sulphate in one tablet: <u>g</u>	mass of $FeSO_4$ in a tablet = $\frac{\text{mass of } FeSO_4 \text{ in the sample} \times \text{average mass of a single tablet}}{\text{mass of the sample powder}}$
The mass of iron in one tablet: <u>mg</u>	mass of Fe in a tablet = $\frac{\text{mass of } FeSO_4 \text{ in one tablet} \times Mw(Fe)}{Mw(FeSO_4 \cdot xH_2O)}$
Percentage error: <u>%</u>	% Error = $\frac{\text{mass of } FeSO_4 \text{ determined by titration} \times \text{advertised mass of } FeSO_4 \text{ per tablet}}{\text{advertised mass of } FeSO_4 \text{ per tablet}} \times 100$

INTERPRETATION of analysis:

[Signatures: We confirm that this is our own work, the use of materials from other sources has been properly and fully acknowledge and that all data obtained are correct.]

Appendix 2. Scheme used to Provide Feedback to Students

Grader's overall opinion on this assignment	Excellent work based on a thorough understanding of the problem posed, demonstrating clear and significant insight and well justified conclusions stemming from balanced argument 90+ points: sophisticated, of highest professional standard 80+ points: striking work demonstrated 75+ points: excellent in all areas.	A good to very good work based on a sound to clear understanding of the problem posed to produce well-supported report ready for submission to virtual client. 60-69 points	A competent to sound written report addressing the problem posed with standard sources. Some areas need improvement. 50-59 points	A basic report, adequately written, but demonstrating only limited or superficial understanding of the problem posed. Report needs several corrections before submission to virtual client. 40-49 points	Poorly written report showing little evidence of awareness of the issue. Report cannot go out to virtual client. 30-39 points: some knowledge, but poorly presented. 20-29 points: answered only in part, flawed. 10-19 points: deeply flawed or unacceptably brief <9 points: Irrelevant or unintelligible.	/100
Experimental Clear and detailed experimental section including all chemicals and amounts needed. Validation of experimental setup included. Preparation of standard solutions included. Well referenced. Experimental description should be repeatable by any qualified person.	Fulfills all the criteria to the left. No or very minimal help of supervisor needed. 14 - 20 marks	Deficient in one area. Only minor corrections and/or help of supervisor needed. 12 - 13.5 marks	Deficient in more than one area; some corrections and or help of supervisor needed. 10 - 11.5 marks	Deficient in more than one area. Supervisor had to correct several parts of experimental description. Supervisor had to help with experimental setup. 8 - 9.5 marks	Deficient in several areas. Significant corrections of supervisor needed. Presented experimental section not acceptable and repeatable. Inadequate. < 7.5 marks	/20

(Continued)

Appendix 2. (Continued)

Background	Fulfills all the criteria (left). Demonstrates a full-mastery of the background material in the chosen area, logically integrating theory and evidence from wide range of relevant sources to address the research question posed. 10.5 - 15 marks	Demonstrates a good understanding of the background material in the chosen area by integrating relevant information from a good selection of relevant sources to address the research question posed. 9 - 10 marks	Demonstrates a sound understanding of the relevant background material in the chosen area through application of an adequate range of standard sources to address the research question posed. May have some gaps or minor misunderstanding/errors. 7.5 - 8.5 marks	Demonstrates a limited understanding of background material in the chosen area through use of a few standard sources, which may not always be relevant to the research question posed. Likely to have significant gaps and/or important areas of misunderstanding or errors. 6-7 marks	Understanding of the relevant background material in the chosen area is not evident. Inadequate. <5.5 marks	/15
Clear detailed background explaining the basis science of the experimental setup chosen. Well referenced. Including brief discussion of key facts and/or theories. Chemical equations included. Logical progression to the experimental setup chosen.						
Risk Assessment	Fulfills all the criteria on the left. No corrections of the supervisor necessary. 7 - 10 marks	Deficient in one area. Only minor corrections of supervisor needed. Understanding of risk assessment demonstrated. 6 - 6.5 marks	Deficient in more than one area. 5 - 5.5 marks	Deficient in more than one area. Supervisor had to correct several areas of risk assessment. 4 - 4.5 marks	Deficient in several areas. Significant corrections of supervisor needed. Presented Risk assessment not acceptable for safe laboratory work. Inadequate. < 4 marks	/10
Practical Work/Data Collection	Fulfills all the criteria on the left. 10.5 - 15 marks	Deficient in one area. Only minor intervention of supervisor during laboratory work needed. Safe handling of chemicals and reliable experimental skills demonstrated. 9 - 10.5 marks	Deficient in more than one area. Some intervention of supervisor during laboratory work needed. No units present. Safe handling of chemicals and reliable experimental skills demonstrated. 7.5 - 8.5 marks	Deficient in more than one area; supervisor had to intervene several times during laboratory work. 6-7 marks	Deficient in several areas. Significant corrections of supervisor needed. Presented experimental skills not of standard expected. And/or not professional behaviour shown in laboratory. Inadequate. < 5.5 marks	/15
The students were organized in the laboratory and worked independently. Experimental skills were of high level and all experimental work was performed safely. General attitude and behaviour in the laboratory was professional. Data presented in clear form including units. Data handwritten as stated.						

(Continued)

Appendix 2. (Continued)

Evaluation of Results	Fulfills all the criteria on the left.	Deficient in one area.	Deficient in more than one area.	Deficient in more than one area.	Deficient in several areas.	/15
Experimental results are evaluated in a clear and organized manner. Potential error margins are justified. Data presentation includes clear working scheme and units.	7 - 10 marks	6 – 6.5 marks	area. Some corrections needed. Units are missing. 5 – 5.5 marks	one area. Several corrections needed. 4 – 4.5 marks	Presented work not acceptable for presentation to virtual client. Inadequate. < 4 marks	
Interpretation	Fulfills all the criteria on the left.	Deficient in one area.	Deficient in more than one area.	Deficient in more than one area.	Deficient in several areas.	/15
Results from analysis and validation experiment have been interpreted correctly. Detailed explanation and discussion have been included. Discussion is put together in a logic and coherent manner. Units have been included.	7 - 10 marks	6 – 6.5 marks	area. Some corrections needed. Units are missing. 5 – 5.5 marks	one area. Several corrections needed. 4 – 4.5 marks	Results misinterpreted. Presented work not acceptable for safe laboratory work. Inadequate. < 4 marks	
References	Wide range of resource material; citations wholly accurate and in correct format, citations match those mentioned in main body of report. 3.5 - 5 marks	Deficient in one area	Deficient in more than one area.	Heavy reliance on few standard sources. Citations do not follow an appropriate style or are incomplete. 2 marks	Poor or incorrect use of materials. Inadequate. <2 marks	/5
Appropriate sources used and correct acknowledgment of source materials. References in consistent scientific style, preferable Vancouver style.		Variety of resource material referenced; citations are mostly correct. 3 marks	of resource material; citations show many errors. 2.5 marks			
Overall Format	Fulfills all the criteria on the left. Report can be send to virtual client without alteration. 3.5 - 5 marks	Deficient in one area	Deficient in more than one area	Presentation of report is just about acceptable to be send to virtual client. 2 marks	Presentation of report is of too low standard to be send to virtual client. Inadequate. <2 marks	/5
Clear overall format. Nicely presented work. Can be given to virtual client without any changes. Well referenced. Guidelines followed. Signed and dated by all group members.		3 marks	one area 2.5 marks			

An additional column would be included for feedback to students