Online Safety Quiz for Interactive Revision Reveals Areas for Laboratory Safety Development in Second-Year Undergraduate Chemistry

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An Online Safety Quiz for Interactive Revision Reveals Areas for Laboratory Safety Development in Second-Year Undergraduate Chemistry

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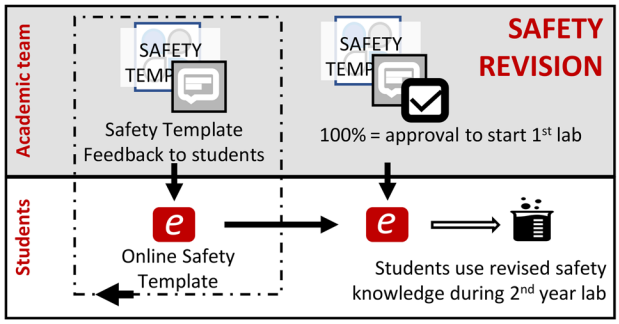
ABSTRACT

General safety and chemical training of undergraduate students is typically held at the first-year level. In this technology report, we propose a flexible strategy to improve students' general knowledge of safety for a second-year inorganic chemistry laboratory. The strategy is composed of an online interactive revision approach through the implementation of a Safety Template quiz, that was easily used on a range of devices and thus flexible for students and academics. Details of the design process, technical aspects of implementation and analysis of student submissions for 2018-2019 are presented. Results showed that low numbers of students (18%) achieved 100% correct completion of the Safety Template quiz with their first submission. However, most students (98%) could achieve 100% correct completion by their third submission. Using an online device agnostic approach, implementation of the Safety Template quiz contributed to some improvement of student knowledge and safe behavior in laboratory sessions. A need was identified for students to regularly and actively revise their safety knowledge in upper level undergraduate chemistry, particularly in the areas of basic chemical knowledge of solvents, maintenance of proper PPE and correct identification of safety equipment.

GRAPHICAL ABSTRACT



KEYWORDS

Second-year undergraduate, inorganic chemistry, safety / hazards, testing / assessment, Laboratory management

INTRODUCTION

Along with general laboratory safety training, chemical laboratory safety programs are aimed at reducing the risk of injury (and illness) by ensuring that all laboratory workers have knowledge of risk management and chemical hazards required to work safely in the chemical laboratory. Major professional bodies, such as the American Chemical Society, the Royal Society of Chemistry and the Royal Australian Chemical Institute, promote the responsibility of education providers for the health and safety of students in their laboratory and ensure that students observe relevant safe working practices.[1-3] Furthermore, reports have sought to identify what topics of chemical safety are important to industry.[4-5] Highly ranked topics included safe handling of chemical materials, accident avoidance and maintenance of proper PPE. Reports of student-centered approaches include an introduction to material safety and data sheets (MSDS),[6] scavenger hunts,[7,8] use of comics[9] and manga (graphic novel),[10] safety trivia games[11] and laboratory chemical safety cases.[12] Elsewhere, a framework for the safety of chemistry students adopts four principles of Safety: Recognize Hazards, Assess Risks, Minimize Hazards, Prepare for emergencies; termed RAMP.[13] In the undergraduate context, compliance with general safety and chemical safety training is often held at the first-year level and can be reserved within the curriculum[14] and as a multiple component activity[15-17] Whereas, during second- and third-

year, chemistry specific safety training is typically associated with an individual experiment. We had taken this approach within a second-year chemistry course along with a compliance declaration and requirement to sign and date a formal 'Safety in the Laboratory' document, which emphasized safe behavior that minimized hazards as a component of the RAMP framework. However, over previous years experienced laboratory teaching staff repeatedly observed that the behavior of the second-year students within a chemistry laboratory (e.g. carrying Pasteur pipettes incorrectly, running, using mobile phones in labs etc.) indicated that their general and chemical safety knowledge needed revision, despite receiving comprehensive training in first year general chemistry. At this time, a university-wide ePortfolio system was adopted by the University in 2016, with the decision to implement the PebblePad personal learning environment, a United Kingdom based system. PebblePad has typically been used as a tool to support reflective thinking, such as development of employability skills and practices or to support laboratory report writing in sciences and engineering.

Herein, we proposed a strategy to revise and improve students' general knowledge of safety within a second-year inorganic chemical laboratory, using PebblePad as an alternative means of delivering safety training revision. Students had completed prior comprehensive safety training during previous studies, such as first-year chemistry, thus the present strategy was to actively revise general knowledge of safety in a chemical laboratory prior to commencement of the second-year laboratory. Details of an interactive revision approach to safety in a chemical laboratory utilizing the online PebblePad system is presented herein.

DEVELOPMENT

In the second-year inorganic course, the student laboratory manual included compulsory reading on general safety hazards, chemical safety (Globally Harmonized system; GHS) and use of personal protective equipment (9 pages). Using this information, students were to revise their knowledge and prepare for the laboratory experiments which involved identification of cations and anions present in inorganic unknown solutions and replacement of the metal in chlorophyll involving the use of organic solvents. Prior to 2018, students were required to sign and date a formal 'Safety in the Laboratory' declaration (see Supplementary Information), prior to commencing the first laboratory session. The

formal 'Safety in the Laboratory' document emphasized safe behavior that minimized hazards as a component of the RAMP framework. Our plan was to introduce an interactive learning activity for safety revision rather than a passive read and declare approach. The activity was developed to occur prior to the first laboratory class to give students a formative opportunity to revise their knowledge of general and chemical laboratory safety. It was hoped that this approach would encourage students to be self-aware, identify potential gaps in their knowledge and be able to use safe practice within the laboratory environment. Accordingly, the previous 'Safety in the Laboratory' statement was aggregated into seven key questions and designed as an online quiz (Table 1).

Table 1. Safety quiz question topics

Question	Type of Question	Topic
1	select correct responses from a list of 11 items	personal safety equipment in laboratory class
2	select correct responses from a list of 9 items	general laboratory health and safety rules
3	select correct responses from a list of 6 items	knowledge of flammable solvents, applicable to laboratory class
4	select correct responses from a list of 11 items	safe behavior and procedures in laboratory class
5	select correct responses from a list of 5 items	safe behavior and procedures in laboratory class
6	match an image number with an image (9 images)	images of safety equipment/features within laboratory class and personal safety equipment in laboratory class
7	select correct responses from a list of 5 items	general laboratory health and safety rules

The quiz questions were in the format of either select correct responses from a list of 5-11 items or match an image number with an image and thus required increased interaction by the students when providing responses. Extracts of two questions illustrating these formats are shown in Figures 1 and 2. The images for question 6 were photographed in the laboratory environment that the students would be doing their laboratory classes in and were constructed for the *Safety Template* as a single JPEG file from a PowerPoint file of photos and text. The quiz question content and style were moderated by another chemistry academic, then created in PebblePad as an *experience template* and entitled 'Safety in the Laboratory Template'; abbreviated as '*Safety Template'*. A dropdown list of

feedback statements for each question (see Supplementary Information) was created for the marker of the *Safety Template*, which was added to during the implementation marking phase.

In conjunction with creation of the *Safety Template*, instruction sheets for accessing and editing the *Safety Template* (Figures S1 and S2) were created for the course site on the learning management system (LMS) along with links to the PebblePad system and description in the student laboratory manual. As part of the development stage, ethics approval was gained to use the student data provided by the user log as well as submissions within PebblePad for research purposes. The student survey that was included in the ethics approval process for a University wide related PebblePad project[18] included questions that were relevant to the course/students within this study.

Question 2: Select which items are not permitted when you are in the chemistry laboratory.
Select the items not allowed in the Chemistry Lab

☒ **Sunglasses**	☐ Safety Glasses	☒ **Thongs**
☒ **Sandals**	☐ Closed Shoes	☐ Laboratory Coat
☒ **Mobile Phone**	☒ **Headphones**	☒ **Electronic Portable Devices (e.g. iPads)**

Figure 1. Question 2 of the *Safety in the Laboratory Template* illustrating the list format; correct answers are selected in bold.

Question 6: Can you identify the safety equipment?

Before you start lab work make sure you know the whereabouts of the safety equipment in the laboratory. To assist you finding them when you are in the lab, match the names to the pictures of the safety equipment.

Select the image number to match with the safety equipment

Image 1 2 3 4 5 6 7 8 9 is the Fire Extinguisher

Image 1 2 3 4 5 6 7 8 9 is the Emergency Fire Alarm Button

Figure 2. Extract of question 6 of the *Safety in the Laboratory Template*, illustrating the image matching format; with correct answers selected in blue.

IMPLEMENTATION

Implementation of the *Safety in the Laboratory Template* using PebblePad occurred in a second-year undergraduate inorganic chemistry course (2018-2019), which included a four-week laboratory component during weeks 2-5 of Trimester 1. At the commencement of the course, all students (n = 234 for 2018-2019 where n = 118 in 2018 and n = 119 in 2019; non-English speaking background: Australian domestic student ratio of 58:42; average age 18-20) had completed a comprehensive safety training equivalent to first-year chemistry level. Furthermore, the students were required to read the chemical and laboratory safety information in their laboratory manual prior to answering the questions in the the Safety Template. Figure 3 summarizes the design process for development and implementation.

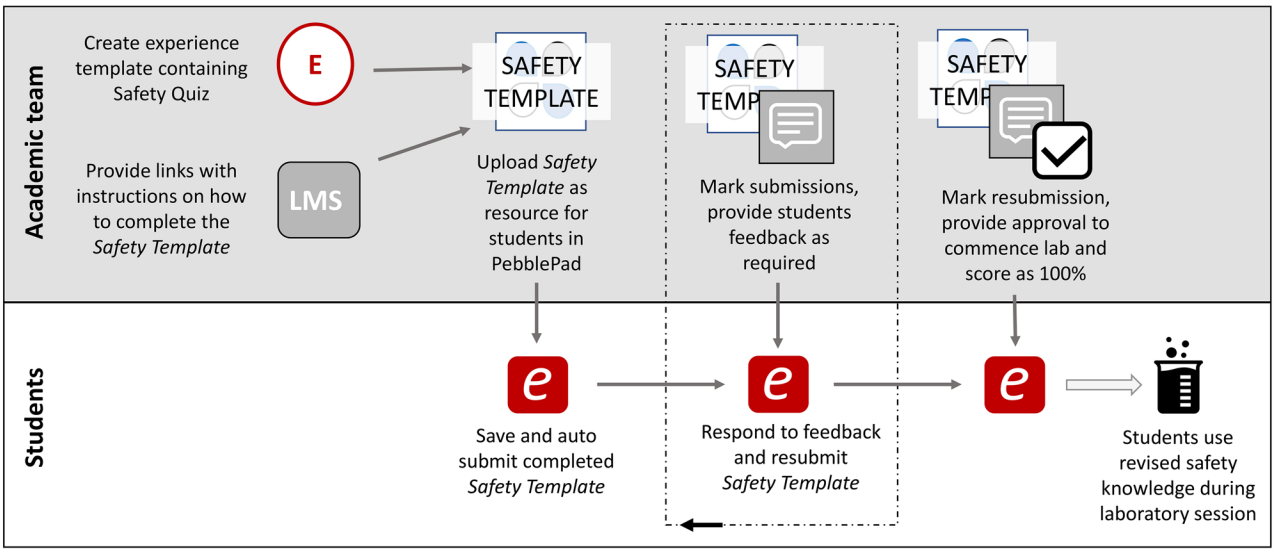


Figure 3. Development and Implementation design process for *Safety in the Laboratory Template*.

Successful completion of the *Safety Template* (to a standard of 100% correct) was a course requirement for all students prior to commencement of their first laboratory class. This requirement was advertised to students for three weeks prior to commencement of laboratory sessions. Each student responded to questions in the 'Safety in the Laboratory Template' and submitted their individual responses in the PebblePad system. The PebblePad system was easily accessible on multiple devices (e.g. iPad, Laptop etc). Students were allowed multiple attempts and given feedback upon each attempt. Selection of feedback comments from the dropdown list facilitated provision of quick feedback by the marker. Timely completion of the *Safety Template* by students was monitored by the course convenor and non-compliant students were reminded through their student email to complete the *Safety Template* prior to their first laboratory session. Occasional technical issues encountered by students were straightforward, such as not saving their responses or not hovering their mouse over clipped text to reveal the full text when in different web browsers (Q6). Upon successful completion of the Safety Template, students were given a grade of 100% and the feedback statement providing permission to attend their first laboratory class.

At the start of the first laboratory sessions (distributed over 2 weeks) students had either 100% successfully completed the *Safety Template* (79% of students), attempted the *Safety Template* but still

had incorrect answers (18% of students) or not attempted the *Safety Template* (3% of students). The latter two groups of students completed the *Safety Template* on the laboratory computers within the first 15 minutes of the first laboratory session and then were permitted to commence the laboratory. First submission of the *Safety Template* by students was monitored across a 4 to 5-week period during the pre-and first scheduled days of laboratory (Figure 4). The total number of submissions by time of day was recorded (Figure 5). Four observations were made. Some students (14%) were very organised and completed the *Safety Template* prior to the start of Trimester. Other students (70%) completed the *Safety Template* prior to their lab session and once they had started formal classes in week 1 of Trimester 1. A third group of students (16%) completed the *Safety Template* within 24 hours of the start of their first scheduled laboratory class. Students first submission of the *Safety Template* quiz was distributed through the time period of 7:30 am to 12:00 am (midnight). Notably 25% of student completed their first submissions outside the standard working day of 9:00 am to 5:00 pm (Figure 5), indicating the flexibility of online approaches to raising safety awareness in students.

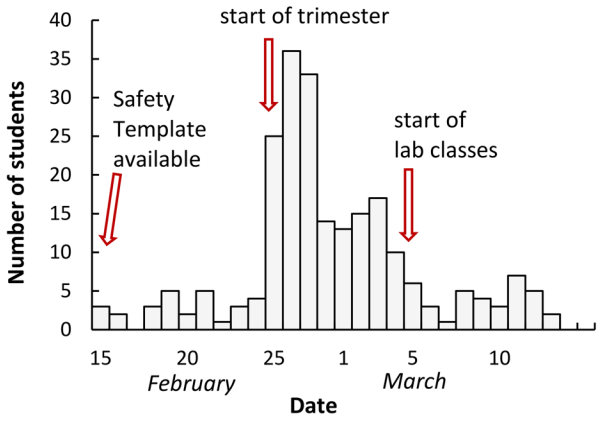


Figure 4. Date of first submission of the *Safety Template* by a student during the periods 15/02/2018-15/03/2018 and 13/02/2019-13/03/2019.

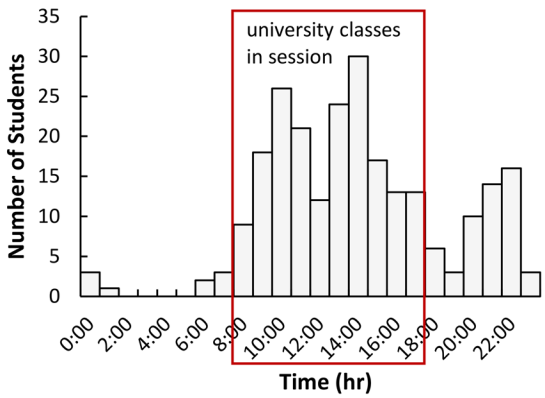


Figure 5. Time of day of first submission of the *Safety Template* by a student during the periods 15/02/2018-15/03/2018 and 13/02/2019-13/03/2019.

Analysis of the incorrect answers indicated that 100% correct completion of the *Safety Template* was achieved by 18% of students on the first attempt, a further 62% of students on the second attempt, 19% of students on the third attempt with 2% requiring four attempts (Figure 6). Students that required more than one attempt, typically got 1-4 questions incorrect on their first attempt, typically reducing it to a single question incorrect (often question 3) on their second/third attempt.

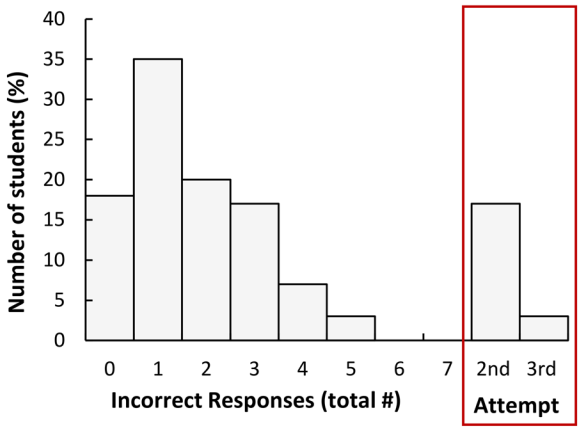


Figure 6. Number of incorrect responses for the first submission and number of second or third submission attempts of the *Safety Template*.

The topic of questions that students had greatest difficulty in recording a correct first response with were the safety and chemical knowledge associated with awareness of items not permitted in the laboratory (Question 2), solvent flammability (Question 3), and identification of safety equipment especially the differences in latex and vinyl gloves (Question 6) (Figure 7). Other typical errors are listed

in Table 2. It was interesting to note that the topic of these questions showed a degree of synergy with the areas of deficit identified by industry reports: [4-5] safe handling of chemical materials, accident avoidance and maintenance of proper PPE.

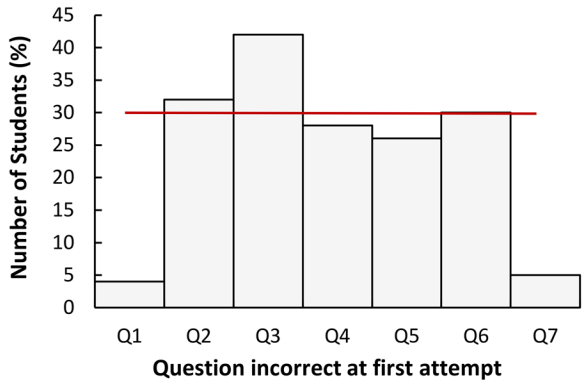


Figure 7. Questions with incorrect responses for the first submission of the *Safety Template*.

Table 2. Common errors for Safety quiz questions

Question	Topic	Common Errors
2	general laboratory health and safety rules	selecting mobile phones and electronic portable devices, headphones as allowed in the laboratory
3	knowledge of flammable solvents, applicable to laboratory class	identifying aqueous solvents as flammable
4	safe behavior and procedures in laboratory class	not knowing which way to safely point Pasteur pipettes when carrying them (downwards vs outwards)
5	safe behavior and procedures in laboratory class	not having read the laboratory manual thoroughly and incorrectly identifying people for accident reporting
6	images of safety equipment/features within laboratory class and personal safety equipment in laboratory class	incorrect glove identification; incorrect identification of safety equipment in the laboratory (e.g. fire alarm button, safety shower)

Other preliminary evaluation of the implementation of the *Safety Template* included students' comments on surveys, such as: 'easy to submit', 'found it easy to access PebblePad through the LMS' and 'lecturer can easily mark work on PebblePad'. It was interesting to note that potentially improved awareness of self-practice within the laboratory environment may have assisted students in the whole laboratory classes experience. Apart from the introduction of the *Safety Template* through PebblePad in 2018-2019, no other changes to the laboratory component of the course or marking criteria for the laboratory reports were made as compared to the 2017 offering. Anecdotally, staff indicated the amount

of unsafe behavior by students, such as running in the lab or carrying Pasteur pipettes incorrectly, was reduced and minimized in 2018-2019 laboratory sessions as compared to the 2017 laboratory sessions.

The most noticeable aspect of implementation of the *Safety Template* was the identified need for student to regularly and actively revise their safety knowledge for chemistry laboratory environments, beyond any general and chemical safety training received in first year. Analysis of the student responses revealed the areas for improvement of laboratory safety in second-year undergraduate chemistry included basic chemical knowledge of solvents, maintenance of proper PPE and correct identification of safety equipment. The low numbers of students that could achieve 100% correct answers on the first submission indicated that student's maintenance of their general safety knowledge within a chemistry laboratory was variable. This is possibly due to the 'casual-part-time' learning activities students experience with chemistry laboratories during their undergraduate studies. From a students and teaching staff perspective, use of an online interactive revision approach to safety in a chemical laboratory (such as the *Safety Template* delivered through PebblePad described herein) was flexible for all users and appeared to contribute to improved student knowledge and safe behavior by students in the laboratory sessions.

FUTURE OUTLOOK

In the future, interactive revision approaches to safety in the chemical laboratory could be created at Year 2 level with more advanced revision at Year 3 and 4 level and thus systematically implemented throughout undergraduate chemistry teaching. We anticipate that this will lead to more awareness of self-practice within undergraduate chemistry laboratory environments and better equip students to think and potentially respond to safety practice as students in their courses and then as graduates within chemistry laboratories.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX. [ACS will fill this in.]

Details of (i) instructions to students for accessing and editing the *Safety Template* in PebblePad, (ii) sample feedback statements and (iii) previous safety declaration for students, (PDF)

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Notes

The authors declare no competing financial interest.

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