Journal of Chemical Health Risks

www.jchr.org

JCHR (2024) 14(5), 230-234 | ISSN:2251-6727

Effectiveness of Experimental Planning Design as a Tool for Safe Use of Toluene with Natural Rubber: Case Study in Buriram Rajabhat University

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(Received: 11 June 2024 Revised: 16 July 2024 Accepted: 10 August 2024)

KEYWORDS

Toluene
Safety
Experiment
Natural rubber

ABSTRACT:

Introduction: Experimental planning design is an important area for research that can be incorporated into the preparatory step of a research project in a chemistry course. Correct handling procedures are necessary for students studying the characteristics of natural rubber. Instruction on laboratory safety can serve as an introduction to the importance of the handling and use of toluene. This work reports on the results from a planning design study. We describe and discuss the necessary steps in the experimental planning design for chemistry students to prevent the release of toxic toluene that may have adverse effects on the students and the environment. The experience was based on a cooperative laboratory experiment with students who would work with toluene in their research. In addition, an activity using toluene was implemented in the planning procedure. We found that students could apply the experimental planning design in subsequent experiments and their research.

1. Introduction

Toluene is used as a solvent to study the dissolution of natural rubber (NR) as a part of studies of the mechanical properties of NR. Graduate chemistry students have to work on a research project in an experimental laboratory where there may be large amounts of solutions and mixture waste from the research. Practically, toluene affects kidney, and liver functions [1]. Consequently, this waste, if not handled properly, may be toxic to human health and contaminate the environment [2]. Furthermore, the laboratory needs to dispose of the waste. Procedures for the use of toluene and the management of hazardous waste in the laboratory.

Students should be advised to use the appropriate quantity of toluene. The fundamentals of safety laboratory practices should be reinforced early in the research course [3]. The priority in handling chemicals is ‘safety first’. Effective safety management should instill confidence in the students, staff, and communities so that those involved can apply self-safety benefit management [4, 5]. Accidents, even if they cause minimal initial damage, if not managed properly, may lead to severe damage. Some incidents could lead to injury, such as chemical splashes into the eyes or chemical spills, with harm being caused to the nervous system. Therefore, it is necessary to instruct students on the causes and effects of accidents because of negligence in safety management. One reported case involved a fire from the organic solvent in the science laboratory, resulting in injuries and property damage [6]. Instruction in the systematic management of safety includes basic directions on personal security and correct waste disposal. A systematic strategy should plan for the prevention of occupational accidents to maintain safe laboratory workplace where the researchers can work efficiently. An online safety video is one form of existing media that can be used to facilitate learning and can be utilized many times [7]. Information can be disseminated using a Material Safety Data Sheet (MSDS) that can guide the safe use of toluene in addition to developing guidelines regarding the use of hazardous substances in the laboratory [8].

The current study created a collaborative experimental planning design including a test case for handling toluene. We believe this instruction provides a useful and effective method to develop an appropriate planning design. Planning in experiments not only encourages students to think critically but also helps them to plan their approach to handling toluene. In the first-year chemistry course, we used direct instruction, handouts, slide displays, and class work. Therefore, we propose a strategy to rearrange

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www.jchr.org
JCHR (2024) 14(5), 230-234 | ISSN:2251-6727

and enhance students' awareness of safety in a fourth-year research project course in chemistry, using experimental planning design as the instrument for safety adaptations. We begin by implementing a planning strategy of safety for the third-year chemistry students that will enhance their awareness and knowledge of proper toluene handling. Although this assignment targets the students working on their research project, it can be expanded to ensure that safety issues are addressed by all students in the laboratory [5]. We introduce the concept of 'experimental planning design', which is intended to work with the existing topic in the research project to complement the concepts and skills the students are expected to learn. The concept of design requires students to understand the technical process as laid out in the brief, the hypothesis of the research project, the physical function in terms of safety, and environmental criteria. The combination of a real situation of an accident in a laboratory is used to tech planning design in an experimental setup [9]. This article describes our attempt to facilitate the safe handling of toluene in a research laboratory using the strategy of experimental planning design to prevent harm from chemicals, considering the source of chemicals, the transit of chemicals through the human body, and personal protection.

We are concerned about the importance of students' health exposure to toluene because often they are exposed to toluene for long periods during their research; thus, we aimed to prevent exposure to the dangers of chemicals by adopting the principle of caution and providing guidelines to prevent harm due to chemical exposure. Students were given suggested topics for a possible design to promote their technical skills in the laboratory and to help them turn the knowledge into practical skills. Therefore, the framework for handling toluene in the research project was designed around a discussion class in the experimental laboratory setting.

2. Objectives

The aim of this study was to describe our attempt to incorporate chemical safety in the research project course using a planning design strategy. We used the strategy based on student self-study to make the students more self-aware [10]. However, safety teaching was embedded deeply and broadly throughout the instruction of the experimental planning design. The student's feedback from this study was carried out at the end of the 2022 academic year.

3. Methods

Developing instructions

We implemented lectures for the research course in the fourth-year laboratory into the third year of studying chemistry to increase the awareness and consciousness of the proper procedures for toluene handling and laboratory safety in an experimental research laboratory. The development of a procedure to encourage student's ideas in designing the experiment, and the problem-solving procedure for the successful results is shown in **Fig. 1.** To ensure learning development, we required students to work in groups of two and to deliver progress report on the experimental planning design. The students were given the same research project brief and tasked with developing the experimental planning design.

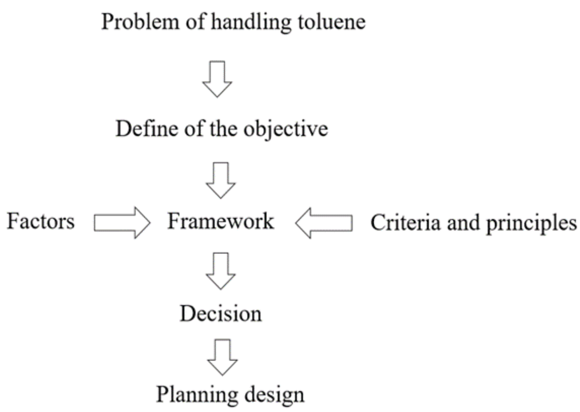

Fig. 1 Scheme of procedure to achieve experimental planning design

The framework was divided into subunits to analyze the cognitive learning in developing the experimental planning design. Students were directed to focus on the main concern of avoiding exposure to the hazards of toluene, minimization of the risk from toluene, preparation for an emergency, health and safety, and discussion of management using toluene in the laboratory.

Meeting attendance

Information was provided to the group on the basic principles of safety in synergy with the experimental planning design of the research project. To This instruction was distributed through four steps involving

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JCHR (2024) 14(5), 230-234 | ISSN:2251-6727

student attendance, as shown in **Table 1**. The students reviewed the many documents related to planning their research. In particular, the delivery of the experimental planning design was supported by the instructor during project. The students were required to present the process of planning design to meet the research project brief. Overall, to develop instructional practices in experimental planning design, we managed to contribute to safety engagement and the acquisition of design skills. The activity engaged the students in interaction to construct the activity based on interconnecting discussion. Presentation was integrated with the methodologies and safety management through reflection on opportunities and alternative perspectives on possible situations in a specific design problem.

However, the important safety management aspects of handling toluene were emphasized to the students, such as how much toluene to use in the laboratory research, how to handle toluene during experimental use, and how to manage any spill or waste of toluene.

Responsibility for evaluation of experimental planning design

Because of the preliminary layout of the experimental planning design, we closely screened the content and determined approximate conditions to the real laboratory. Information about situations important and necessary to the whole research experiment was given to students for clarity in their design. This included: comment and advice on what modifications, if any, should be made to improve their design; the importance of developing safe practices while using toluene; the procedure for dissolving NR in toluene; and consideration of connecting concepts and scientific equations.

Table 1 Instructional practices implemented to support learning and development of experimental planning design skill

Instructional practice	Description	Frequency
Direction of the experi-mental planning design	We provide a short introduction to the topic that students should do in the period before the work on a research project. Students were invited to attend and contribute, and students had sight of the problem and response given the outline list, concerning toluene that students have to learn to make the preliminary layout plan.	During the first period of research project assignment in third-year
Progress meeting	Students attended the meeting to present progress against received feedback from their preliminary layout plan. Discussion for improvement of the content of the documents.	Three weeks after the first instruction
Preliminary work in laboratory	Monthly 1 hour work sessions to deliver technique content relevant to the research project and to complete material used in the research.	Last month before the fourth-year chemistry course
Design development and submission	Meeting to discuss and approve the proper planning design	Last week before the fourth-year chemistry course

4. Results and Discussion

For the actual preliminary layout plan, only two different types of instructional practice (as shown in **Fig. 2**) were in the progress meeting.

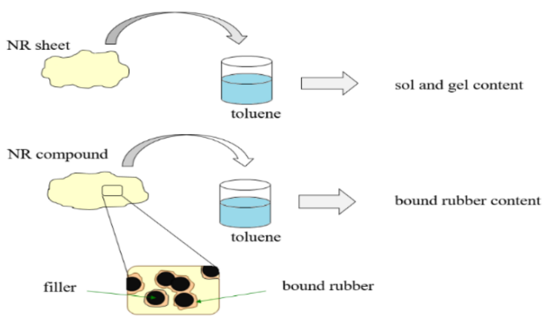

Fig. 2 Example of experimental planning design

We motivated students on the importance of evaluating the factors in studying parameters from the sol and gel contents, so later, the students presented three equations in the planning design to demonstrate deep and meaningful learning regarding that parameter. The students knew that the research project used toluene to soak the NR specimens.

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Typically, NR consists of sol and gel [11, 12] with the gel fraction determined from dissolving NR in toluene for 16–20 hours. The solution or sol fraction (25 mL) was separated from a total amount of 100 mL of sol and gel and then dried. The sol and gel contents were calculated using equation (1) and equation (2), respectively [13]:

$$W_{sol} \times 4 = W_{dried\ sol} \quad (1)$$

$$\%\ gel = \left(\frac{W_{NR} - W_{dried\ sol}}{W_{NR}}\right) \times 100 \quad (2)$$

where W_{sol} is the weight of the dried sol, W_{dried} sol is the weight of the total dried sol, and W_{NR} is the weight of the NR specimen.

For the NR compounds, rubber-filler interaction is the so-called bound rubber resulting from the process of rubber compounding with the gel fraction. The bound rubber content was determined based on equation (3) [14, 15]:

$$\%\ Bound\ rubber\ content = \frac{W_{fg} - W[m_f/(m_f+m_r)]}{W[m_f/(m_f+m_r)]} \times 100 \quad (3)$$

where W_{fg} is the weight of the rubber-filler gel, W is the weight of the NR compound specimen, and m_f and m_r are the weights of the filler and rubber in the NR compound, respectively**.**

The students carried out the preliminary laboratory test to inform their submission on the experimental planning design. Discussion took place during the laboratory session, with some excitement evident regarding the safe use of toluene as they began handling it. The laboratory session was scheduled at the end of the semester rather than at the start of the fourth-year to provide a more casual setting. In the experiment, toluene was provided in a sealed bottle. From the MSDS specifications, some main characteristics were its density (0.87 g cm^{-3} at 20 °C) and that it is hazardous to the skin, an irritant and a highly flammable liquid and vapor. Providing this information early in the research course helped to quickly determine how much time was needed for the experiment.

Furthermore, since MSDSs are available online, the students could access the information easily along with extensive details regarding toluene safely. The students sent their layout plan for evaluation that was checked for the proper flowchart of details of the procedure against the questions provided, as shown in **Table 2**. Following the submission of the experimental planning design at the end of the semester, the completed preliminary laboratory testing was available as part of the supporting information attached to their documents.

Table 2 Using toluene: Safety perspective questions and thematic units

Questions	**Typical thematic units**
How long is needed to do the experiment	3 hr. for soaking and collecting the specimens. Approximately 2 times per working sample for the samples preparation.
Why is it necessary to use personal protective equipment	Inhalation of volatile toluene
How can you protect yourself in a real-work situation each day in the lab	Nitrile gloves, carbon face mask, and protective goggles
How much toluene will be used for the complete research project	Approximately 2.5 L toluene (4 specimens of NR × 100 mL = 400 mL) and (4 specimens of NR compound × 5 formulas of compounding x 100 mL = 2,000 mL)
How do you manage the toluene waste	Transfer the toluene residue to fill up to three-quarters the volume of a sealed glass bottle and store the bottle in a plastic container

Three weeks after instruction for the progress of the experimental planning design, the students submitted the layout plan for proceeding with the experiment. These activities encouraged students to demonstrate their communication skills and knowledge. The results showed that student's attitudes toward the laboratory produced more imaginary scenarios regarding the scale and type of research. In addition, we found that the students were motivated by doing the planning by themselves rather than just giving them the instructions.

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5. Conclusion

The role of the instruction was to support the students in planning the investigation of this assignment task and to help them understand when the principle had been applied appropriately in their preliminary laboratory testing. This was not a simple task and could only be taught after reliable combined key information had been supplied to the students. This comprehensive set of handling instructions provided a systematic approach to the experimental planning design. This study developed the proper safety procedures for handling toluene in a student research class. The strategy we applied added the instruction in the preparation by the students for the research project and we assessed the effectiveness of the instructional practices. We found that by using the developed framework, the students could successfully submit a practical design was an improvement from the preliminary layout plan and laboratory testing.

6. Suggestions

The assignment of the experimental planning design was undertaken by the research project students at the beginning and end of the 2022 academic term. These data represent the design planning ability of students after brief safety instruction. These results will be used to extend the real situation of project research. Students' perceptions about laboratory safety using toluene and results incorporated into the experimental planning design need to be investigated from the reflection of applied safety on their experience throughout their respective experimental research project.

7. Acknowledgements

This research was supported by Buriram Rajabhat University, Sakon Nakhon Rajabhat University and Kasetsart University Chalermphrakiat Sakon Nakhon Province Campus.

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