Decline in risk perception when using chemicals as tools - suggestions for laboratory safety
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We collected and analyzed reports of accidents over a four-year period at a Japanese university. Focusing on accidents resulting from contact with chemical substances among accidents in academic research, we found that accident victims were more likely to be in biology, physics, or other non-chemistry fields relative to chemistry-related fields, and that the number of accident reports tended to increase among those with more research experience. In addition, of the accidents involving the handling of chemical substances, 58.2% of the total cases resulting in accidents involved the use of chemical substances as tools in the experimental process, rather than being the actual subject of the research. These results show that today’s advanced research is closely related to the use of chemical substances as tools, underscoring a need for the understanding of the hazardous properties of chemical substances through basic education about chemical substances and ongoing accident prevention efforts in academic research. The use of chemical substances as tools in experimental research was found to be closely related to a decline in risk perception, and investigation of this mechanism should contribute to future safety education efforts.

Keywords: Risk Perception, Accident Analysis, Safety Education, Laboratory Safety

1. Preface

1.1 Collection of accident information at universities

Since the conversion to independent administrative institutions in 2004, Japan’s national universities have been governed by the Industrial Safety and Health Law, which was previously applicable to private-sector corporations. In response to the application of this law, the university in this accident survey report has established special departments focused on safety and health management. Recently, the establishment of an accident information sharing system among several national universities in Japan has come under review.

At Osaka University, a monosilane gas explosion during experimental research killed two people in 1991\(^{1}\). Following the occurrence of accidents in Taiwan that resulted in fatalities, research focused on lab safety was conducted\(^{2}\). However, there has not yet been a process established for sharing serious accident information between universities. Researchers or practitioners interested in the issue have obtained information regarding serious accidents from self- or mass media reports.

The collection of accident information at academic research institutions lags behind that of other settings such as hospitals, airlines, and chemical plants. In this research we focus primarily on analysis for consideration of future policies, from the perspective of an approach to sharing and analyzing systematic accident information.

1.2 Safety management issues at universities

Many accidents of varying degrees of seriousness have occurred at universities and other academic research institutions. Universities are research sites that test and extend the boundaries of contemporary knowledge and technology. Based upon this viewpoint, universities are inevitably associated with risk\(^{3}\). Accident case data from universities and research institutions, spanning a wide range of major fields, has rarely been accumulated and analyzed in organizations as a whole. At the general university level, it is often difficult to systematically collect and analyze information regarding accidents or to utilize the knowledge obtained for educational purposes.

One possible explanation for this state of affairs is that university laboratories have a strong tendency toward uniqueness and independence in their organizational operations. Secondly, education and research in academic settings is led by experts in their respective research fields. Given the expertise of the investigators, any occurrences at universities and other academic research institutions are considered to be an internal issue within the research lab or the academic department alone, as long as the accident does not result in serious injuries or fatalities. Lastly, universities can be considered to be environments with vague
differentiation between employees and non-employees. For example, in the teaching assistant system, students are often simultaneously considered to be non-employees and employees who participate in teaching. There have been recent cases in which the legal handling of safety and health issues has differed between teachers as employees and students, who are considered to be non-employees. Therefore, each member of the academic institution may not have an awareness of their individual responsibilities regarding laboratory safety and protocol following accidents.

1.3 Spread of chemical use in research

At Japanese universities, efforts in accident prevention begin in the first year when a student is assigned to a research lab. In the fields of chemistry, biology, and physics, experts generally oversee accident prevention efforts in their laboratories. Based upon this system, as students advance and as their expertise increases, the content of their safety education varies. For example, in the Lowry (1978) education system, education targeted at upper level students was found to be effective and can be regarded as a good practical example from the perspective of timing of the learning.5,19

Chemical expertise is used in many research sectors as a basis for individual laboratory work. For example, DNA staining is used in biology, and chemical substances are used as basic solvents in physics. Chemistry is a basic science with a huge impact on society.6 At the same time, the assurance of safety protocols among laboratory staffs is also expected. The Chemical Safety Levels (CSLs) proposal applies to chemical risk management in research sectors other than chemistry, such as microbiology and biomedicine.7 Therefore, the present study also considers the prevention of laboratory accidents resulting from the handling of chemical substances in cases not limited to the academic field of chemistry.

1.4 Risk perception regarding chemical substances

In terms of safety education, knowledge is first acquired about the chemical properties of each substance and then applied to accident prevention. Therefore, education regarding the hazardous properties of chemical substances and industrial health and safety guidelines can be expected to aid in accident prevention. In general, knowledge can be broadly divided into two categories: 1) declarative knowledge, which includes facts that are universally known, and 2) procedural knowledge, which involves an understanding of how to perform tasks that often occur automatically and cannot be specifically described. Knowledge of chemical properties falls into the declarative knowledge category, while experimenting and research skills required for handling tools used in experiments are involved in procedural knowledge. Accident prevention has historically been considered to combine both declarative and procedural knowledge through the practice of experiments. However, the acquisition of knowledge does not necessarily provide an accurate estimation of risks and safe behavior in the laboratory setting.

In Slovic’s (1987) work on the recognition and judgment of risk, he proposed that cognitive factors, such as prior knowledge, and emotional reactions such as fear, both play a role in risk assessment.5 In one study, Mertz, Slovic, and Purchase (1998) clearly showed a difference in risk perception between senior managers, researchers, and the general population regarding chemical substances, suggesting that risk perception can differ across individuals.9 In addition to the presence of knowledge, there is the possibility that cognitive factors, such as attention and risk perception, also have an effect on human behavior. Such factors should be considered for the prevention of accidents when handling chemical substances, and it is important to classify chemical substances based on our knowledge of their properties.

1.5 Study objectives

In this study, we seek to investigate accident data to explore the effect of risk perception on human behaviors. A primary goal of this research is to assist policymakers in the consideration of future regulations to prevent laboratory accidents in academic institutions. The objectives of the present study are to: 1) continuously use collected cases to understand trends, rather than relying on the personal experience or self-reports of teachers, and use this information as material for university-wide safety education, 2) understand the trends in laboratory accidents in comparison to other research fields, particularly since the use of chemical substances is not limited to chemistry majors, and relay this knowledge to university safety education to assist in accident prevention efforts; and 3) provide a novel framework for promoting awareness and understanding of key issues, including the relationship between chemical substances and human behaviors.

2. Method

Data were collected by the department in charge of safety and health of a national university. For our analysis, we focused on accidents that had been reported during the time period between April 1, 2004 and March 31, 2008. All accidents that were reported involving approximately 20,000 students and approximately 7,000 teachers and staff were included in the analysis. All injury and non-injury accident cases were included in the analysis. Recreation accidents, traffic accidents, natural disasters, and accidents in university hospital were excluded from the analysis.

3. Results

3.1 General trends

The overall trend for reported cases during the four-year period from April 2004 to March 2008 is shown in Fig. 1. About half (55.3%) of reported cases involved experimental research in which tools were used for experiments and analysis, that involved chemical handling.
or chemical-related incidents, and that involved fires. The next most common cases were falls and those related to general equipment including office stationery. For subsequent analysis, we focused on the 91 cases of accidents related to chemical substances.

### 3.2 Classification by academic major and status at the university

To clarify the degree of involvement of the researcher's experience or position in reported cases, we analyzed researcher characteristics. The data were divided with the following categories: 1) students or teachers/staff; and 2) academic major, which was inferred from the affiliation name of the reported case’s victim or of the reporter. As shown in Fig. 2, results of this analysis indicate that in chemistry-related fields, many reported accident cases involve undergraduates and graduate students, while few cases are reported among teachers and staff. In contrast, biology-related and physics-related fields showed a particularly large number of accident reports among teachers and staff relative to chemistry-related fields.

### 3.3 Classification by chemical type

Figure 3 summarizes the chemical substances actually used in 100 or more laboratories at the targeted university. Fig. 4 shows the chemical substances used at the time of the accident, which do reveal a common pattern. As seen in Fig. 3 and Fig. 4, hydrofluoric acid does not fit the common pattern between chemical substances most often handled (i.e., Methanol, Chloroform) and accident occurrence. Although there are few laboratories using hydrofluoric acid, some accidents involving this chemical substance were reported.

### 3.4 Chemical substances as the research subject

We focused on whether or not the chemical substances involved in the 91 cases were the subjects of the research. Results of the analysis revealed that some chemical...
substances involved in the accidents were not used as the actual subject of the research. In such cases, the chemical or physical properties of the chemical substance were utilized to maintain the temperature of the research object, or to perform melting or dyeing.

We asked three experts in charge of university safety management (Judge A: psychology, Judge B: physics, and Judge C: chemistry) to independently classify each case into one of three categories: 1) chemical substance that caused the accident was the subject of the research; 2) chemical substance that caused the accident was not the subject of research but was used as a tool; and 3) undetermined. Cohen’s Measure of Agreement (kappa) was used to determine the strength of agreement of the three ratings. Kappa indices (k) were 0.73 between Judges A and B, 0.67 between Judges B and C, and 0.66 between Judges A and C, k = 0.66. Overall, these results show a high level of agreement between experts.

Since there were no cases in which the three judges made significantly different judgments, we determined that at least two judges arriving at the same decision would constitute a final judgment. Final results showed that there were 23 cases in which a chemical substance that caused the accident was the subject of research, 53 cases in which a chemical substance that caused the accident was not the subject of the research but was used as a tool, and 15 undetermined cases. Overall, 58.2% of the total cases did not involve chemical substances that were the subject of research.

As shown in Fig. 6, results were divided by academic major. Chemistry faculty and students were more likely to use chemical substances as a subject of research, whereas biology/physics faculty and students were more likely to use chemical substances as a tool. The data were divided according to academic major, which was inferred from the affiliation name of the reported case’s victim. Two cases

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**Fig. 3** Number of laboratories using chemical substances measured by the Working Environment Measurement Act (Japanese act, excluding gaseous substances. As of 2008)

**Fig. 4** Chemical substances that caused accidents (2 cases or more)
Note: Chemical substances marked with an asterisk (*) are not items targeted for the Working Environment Measurement Act, and, therefore, are not included in the aggregate calculation in Fig. 3.
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seemed to bridge chemistry and physics, and chemicals in both cases were used as the subject of the research. These cases were consistent with the overall trend observed in this study.

4. Discussion

4.1 Caution regarding aggregate calculation

We will discuss the classification of the accident reports aggregated and their practical application toward safety education, but first, two points of caution. First, Dekker (2003) pointed out the risk of bias that can arise in surveys of causes depending on accident classification,10) and we wish to point out here that classification of accidents is not the primary objective of this research. The model of human behavior derived from the aggregate analysis or classification of accidents, which does not encompass all types of accidents, cannot provide a unified explanation of accident mechanisms and prevention approaches. Therefore, the results obtained from this study require consistent and ongoing verification.

Secondly, the data collected in this study did not include certain parameters, such as the length of time in which researchers were performing operations. Such factors would ordinarily be considered to be related to exposure and increased risk of accident.

4.2 Spread of chemical accidents

As shown in Figure 1, combining tools for experiments and analysis (injury from tools used during experiments and analysis, injury from chemicals, fires, apparatus-related injuries, substance leaks, and needle sticks) accounted for 55.3% of the total number of accidents, confirming that laboratory safety is a large element in risk management at universities. As shown in Fig. 2, accident victims were more likely to be majors in non-chemistry fields, such as biology or physics. In addition, there were more reports of accidents among victims engaged in biology and physics research for many years, suggesting that the problem is not related to chemistry alone.

An analysis of chemical substances related to accidents (see Fig. 3 and Fig. 4) shows that, although the number of research labs using hydrofluoric acid was limited (i.e., 100 or fewer labs), the number of accidents involving this substance was strikingly high. Four of five accident cases involving hydrofluoric acid occurred in graduate school. One reason for the increased incidents in graduate school could be the use of more hazardous chemical substances than during undergraduate studies. Nevertheless, it is likely that safety education or safety culture at the institution were
lacking, and that this contributed to the cause.

We could not specify the number of laboratories which used phenol because this substance is not a specific target for work environment measurements. However, the frequency of its use in biology-related fields is normally high, and accidents involving chemical substances can occur outside chemistry-related fields. Results show that accident occurrence does not depend solely on the amount of chemical used, the duration used, or the number of times used. These results suggest a relationship between occurrence factors and experience with the substance.

### 4.3 Chemical substances as tools, and risk perception

Figure 5 shows that a high percentage of chemical substances were not used as the actual subject of the research. In specific cases, the chemical properties or physical properties of the chemical substance were used to maintain the temperature of the research object or to perform melting or dyeing (i.e., use of the substance as a tool). Nevertheless, it should be noted that uses of the same substance may vary by major.

Based upon the present results, it is important to consider the benefits and drawbacks of using chemical substances as tools. In advanced research, when new discoveries or technologies come into existence, it is not always necessary for the researcher be fully conversant with areas other than their specific area of interest. A benefit of a chemical tool is that it has a function that is already known and can be utilized to achieve research objectives. If attention is focused on only that function and no attention is paid to the risks of the chemical use, the chance of an accident may increase. Thus, there appears to be a decline in risk perception when chemicals are used as tools in the laboratory setting. If an accident occurs because the researcher focuses on the knowledge of his or her specialized area but has insufficient knowledge about peripheral areas, this situation is analogous to an individual falling from the top of a high ladder where he cannot see the surrounding area. Thus, one interpretation for the pattern depicted in Fig. 6 is that biology/physics faculty and students use chemicals but are less knowledgeable about them and probably do not consider safety during their work. Regarding the use of chemicals as tools, it appears that a culture of safety does not currently exist and that safety protocols were only weakly considered.

### 4.4 The cause that a chemical substance becomes the tool

The relationship between risk perception and the tool function of chemical substances can be considered as follows. When focusing on the tool function, the importance of obtaining knowledge (including that regarding safety) is reduced. As a result, risk perception also deteriorates, creating a situation that can trigger an accident. However, it is impossible to clarify whether knowledge regarding safety of the chemical substance was not obtained, or if knowledge regarding the safety of the chemical substance was obtained, but operations became too familiar. More investigation is needed to examine such possibilities.

In this research, we emphasize that an approach to prevent accidents should not be limited to teaching about the properties of chemical substances, but should also examine the concept of using chemicals as tools, to ensure that education is also provided from the perspective of risk perception. This approach applies to chemical knowledge for non-chemistry majors and to knowledge of non-chemistry fields for chemistry-field majors. In science and technology aiming for safety and comfort, reducing known risks is an important responsibility for those in academic research.

### 5. General discussion

Universities are settings for education and research, and the prevention of accidents requires consideration by the experimenter as well as the entire administration of the institution. In the present study, we focused on using chemicals as tools to incorporate risk perception at the individual level into a discussion of accident prevention. Thus, we reconsidered accident prevention from the perspective of the relationship of both students as well as teachers providing guidance, and have identified three different subgroups of teachers and students. First, some teachers have the knowledge or perceive the risks associated with chemical substances, and students typically do not. Secondly, some teachers or students do not have the knowledge or perceive the risk of using chemicals as tools. Third, some teachers and students do possess the knowledge and perceive the risk of using chemicals as tools, yet accidents still occur.

In the first subgroup, in the cases where students caused accidents when using chemical substances as a tool, the students did not appear to have the knowledge or did not perceive the risk of using the chemical substances. Focusing on the teacher who guides the student, this teacher may not be aware that the student does not recognize the risk. As an educational intervention for this subgroup, there appears to be a need for safety education for the student and awareness by teachers of the possible risk perception gap between the teacher and the student. In contrast, in the second subgroup, both teacher and student use chemical substances as a tool in the research lab or research sector, and some accidents still occurring. Accident reports that can be inferred as due to the use of a chemical substance as a tool reveal two approaches for accident prevention, by clarifying the relationship between teachers and students.

We can also use these combinations of subgroups to investigate accident cases traced to reasons other than the use of chemical substances as tools. Research and development in new fields in which knowledge regarding risks cannot be sufficiently obtained at the present time, such as potential risks associated with nanomaterials, can be included in the third scenario. Situations in which both teachers and students fail to wear protective gear or leave a fume hood wide open while continuing operations would also correspond to the third scenario. These cases require consideration of accident prevention from the perspective
of human factors focusing on human error and/or rule violations. Given the findings of the present study, we believe that a safety education approach should take the above teacher/student combinations into consideration.

In general, universities handle a wide variety of chemical substances. Consideration of the kind of safety required in university academic research is important for the implementation of better safety education. A university should not be viewed as an academic research environment without risk. Rather, it should be a place for academic research based on an understanding of the risks involved in science and technology, while making efforts to manage and decrease risks to an acceptable level. We take the position that understanding the properties of chemical substances, particularly when they are used as tools, can help ensure safety and aid in promoting science and technology.

6. Conclusion

Of the accidents involving chemical substances, cases involving the use of chemical substances as tools for experimental research were more frequent than cases using chemical substances as the actual subjects of the research. Since the ratio of accidents due to chemicals used as tools differed depending on student major, there appears to be an educational need for non-chemistry-related majors. Specialists in chemistry could perhaps provide education to students for a better understanding of using chemicals as tools in order to assist in accident prevention efforts.

The use of chemical substances as tools in experimental research is closely related to cognitive factors, and investigation of these mechanisms could contribute to safety education. It is recommended that an emphasis be placed on the function of chemical substances in order to promote familiarity with their use. Based upon our research findings, the use of chemicals as tools appears to be linked to a decrease in risk perception and may therefore be involved in triggering accidents in laboratory settings. In conclusion, we recommend utilization of an educational approach focused on the prevention of chemical substance accidents from a cognitive perspective.

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