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RESEARCH ARTICLE

Knowledge Levels and Safety Culture of Science Center Instructors in Laboratories: An Analytical Study from Türkiye*

Cansu Aydın Emektar[1] • Havva Yamak[2]

[1]The Scientific and Technological Research Council of Türkiye, Ankara/Türkiye
[2]Gazi University, Faculty of Education, Department of Math and Science Education, Ankara/Türkiye

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ABSTRACT

This study examines the laboratory safety culture levels of science center instructors in Türkiye by analyzing their knowledge, practices, and preparedness related to science laboratory activities. Using a qualitative single case study design, data were collected through pre-interviews, observations, and post-interviews with two science instructors who work at the science center. The data were analyzed using descriptive analysis, resulting in five main themes: general safety measures, educational level of the science center instructors, emergency planning, preparedness for potential incidents, and instructor roles. The findings show that instructors demonstrate strong awareness of basic safety procedures, including chemical handling, equipment control and classroom management during laboratory activities. Safety practices were effectively integrated into the teaching process before, during, and after experiments. However, the results also reveal significant limitations in terms of written safety guidelines, systematic emergency planning, and formal emergency training. Although instructors demonstrated proactive behavior and effective risk management during experimental applications, their preparedness for emergency situations—such as knowledge of emergency exits, fire equipment, and first aid materials—was insufficient. These findings highlight the need for structured safety training programs, improved emergency preparedness, and standardized safety protocols within science centers. The results are discussed in relation to existing research on science center instructors, emphasizing the importance of strengthening laboratory safety culture to enhance the quality and safety of science education in informal learning environments.

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1. Introduction

Children are naturally curious and tend to explore their surroundings and ask questions from an early age (Sawyer, 2014; Vygotsky, 1978). Schools provide structured education during this process, but it may not be sufficient for science education. Students need environments where they can directly experience science and find courage (Falk & Dierking, 2000; Hofstein & Lunetta, 2004; Singer et al., 2006). At this point, informal learning environments outside of school are becoming increasingly important (Sözer & Oral, 2016). Science centers are one of the most effective examples of these environments (Bozdoğan, 2008; Çığrık & Özkan, 2016; Heper, 2023; Pilo et al., 2011; Quistgaard & Højland, 2010; TÜBİTAK, 2022; TÜBİTAK Science and Technology, 2024).

Science centers are defined as institutions that support science, mathematics, technology, and engineering education through interactive exhibits, devices, and activities (Hülagü, 2018). These centers aim to raise curious generations and,

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Correspondence
E-mail address: cansu.aydin1998@gmail.com

unlike traditional education, encourage unplanned, individually controlled learning. Environments such as streets, parks, and museums also contribute to informal learning (Sözer & Oral, 2016). Science centers, with their innovative approach, attract visitors to the world of science through hands-on exhibits, science shows, and rich programs (Quistgaard & Hojland, 2010; TÜBİTAK Science and Technology, 2024).

These centers offer opportunities for scientific discovery without the pressure of grades and increase connections to school lessons (Bozdoğan, 2008; Pilo et al., 2011). They raise scientific awareness among visitors of all ages (children, adults, families, teachers) and make learning a way of life (Karadeniz, 2009; TÜBİTAK, 2022).

The number of science centers in Türkiye is increasing; TÜBİTAK has been providing support since 2008, with the first example being the Konya Science Center. There are currently 14 large-scale centers (TÜBİTAK Science Centers, 2024). Workshops (e.g., Design, Deneyap Technology, Mathematics, Astronomy, Natural Sciences Workshops) are heavily featured in these centers, and TÜBİTAK supports content development and equipment modernization (Heper, 2023; TÜBİTAK, 2022).

Science education is the area where out-of-school environments are most actively used (Çığrık & Özkan, 2016). Science lessons require discovery, observation, and analysis, but they are limited in schools due to a lack of laboratories, insufficient resources, and a heavy curriculum (Can et al., 2013; Ministry of National Education, 2018). Science centers fill this gap; students understand topics better by conducting experiments related to daily life (Coşkun, 2017; Keskin Geçer, 2018; Kırpık & Engin, 2009; Tekbıyık & Ercan, 2015). Laboratories enable active learning and develop scientific thinking (Şimşek & Çınar, 2013).

This research evaluates the level of science laboratory safety at a science center in Türkiye. Objectives:

- To determine the level of knowledge of instructors regarding laboratory safety.
- To identify the current safety situation during science applications.
- To examine the laboratory practices through observations and interviews were conducted by the researcher.
- To propose a laboratory safety training model to support the professional development of science center instructors.

Science laboratories encourage learning and increase motivation (Yalın, 2001). Safety is a critical element of the educational process (Hofstein & Lunetta, 2004). Most accidents result from inadequate precautions and instructor knowledge gaps (Sawyer, 2014; Sevian & Talanquer, 2014). Instructors' knowledge of current protocols and professional development are important (National Research Council, 2011; Singer, 2013). In Türkiye and globally, science center instructors are expected to possess competencies in laboratory safety, emergency preparedness, and effective science communication (National Research Council, 2011; Singer, 2013). Research indicates that while instructors generally have basic safety knowledge, gaps remain in emergency planning and hands-on preparedness (Singer, 2013).

This research will develop the safety culture in science centers, prevent accidents, and reveal the level of instructor knowledge. The results will guide strategies and improve the quality of science education.

This study aims to examine the safety level of science laboratory practices conducted in workshops at science centers and the level of knowledge of instructors involved in this process regarding laboratory safety. The main research question is stated as follows: “What is the level of science laboratory safety in workshops at science centers, and what is the level of knowledge of instructors?”

The research focused on the following sub-questions in order to answer the main research question:

- What is the level of knowledge of instructors working in science centers regarding general safety measures for science laboratory practices?
- What is the level of training received by instructors for science laboratory practices?
- What is the level of preparedness of instructors regarding emergency plan preparation?
- What is the level of preparedness of instructors for possible incidents?
- What are the roles assumed by instructors in science laboratory practices?

The research is based on the following assumptions: It is assumed that the instructors gave sincere and honest answers to the questions asked during the interviews. It is assumed that the researcher's observations were unbiased and impartial. It is assumed that the selected activities were appropriate for science laboratory applications. It is assumed that the laboratory environment provided the same physical conditions for each experiment. Furthermore, it is assumed that the science center instructors were of equal level in terms of laboratory training.

The research was conducted within certain limitations. The study was limited to only one science center. The study was restricted to the practices carried out in the Life Laboratory Workshop at this center, as it is the laboratory most frequently used by science teachers. Only two instructors were interviewed within the scope of the research, and one experiment conducted by each instructor was examined. Furthermore, the research was focused on activities included in the science center's activity calendar for the specified month, since science centers implement laboratory applications within pre-determined weekly and monthly schedules.

2. Method

The study protocol was approved by Gazi University Ethics Committee with the decision number E993857 on 11.07.2024.

2.1. Research Design

This study aims to examine the level of knowledge of instructors regarding laboratory safety and the current status of safety measures during science applications at science centers. A qualitative research method was adopted in the study, and the data collection process was conducted through interview and observation forms developed by the researcher.

Qualitative research aims to deeply understand the meaning, process, and context of a phenomenon (Creswell, 2007; Seale, 1999). Accordingly, in this study, the knowledge levels of instructors were determined through pre-interviews, observations were made during the application, and short interviews were conducted after the application. The data obtained were evaluated using descriptive analysis methods; themes, categories, and codes were created.

A case study design was preferred in the research. According to Merriam (2009) and Yin (2009), a case study allows for an in-depth examination of a specific phenomenon within its real-life context. In this study, the knowledge and attitudes of two science instructors at a science center regarding laboratory safety practices were observed and analyzed in their natural environment.

A single case study (Creswell, 2007) was used among the types of case studies. This is because the research focused on the laboratory safety practices of two instructors working in the same context and aimed to understand this single case in depth. Data collection tools were developed based on expert opinions and finalized after a pilot application.

Consequently, this research was conducted using a single case study design to understand the current state of laboratory safety processes in science applications carried out in science centers, the knowledge levels of instructors, and their approaches to safety.

2.2. Study Group

The study group for this research consists of two science center instructors selected using purposive sampling. This method, frequently preferred in qualitative research, allows the researcher to select participants who best represent the phenomenon and can provide in-depth information (Creswell, 2007; Merriam, 2009; Patton, 2002).

In this study, two instructors were selected through criterion-based purposive sampling to ensure a clear understanding of the research question. Both participants work at a long-established science center in Türkiye and share similar qualifications: they are graduates of science education programs, have comparable coursework backgrounds, and have received similar professional development training at the science center. Additionally, during the study period, both instructors were responsible for chemistry-oriented laboratory activities, which ensured comparable instructional content and laboratory conditions.

However, the instructors differ in their levels of professional experience; one has several years of experience in laboratory-based activities, while the other is relatively new to the role. This difference provided diversity in understanding how laboratory safety practices are reflected in the science center. The science center was selected because it includes a dedicated life sciences laboratory—an uncommon facility in many centers—and is easily accessible to the researcher, enabling in-depth observations and interviews.

The reasons for selecting the science center included the continuity of laboratory activities, the availability of similar teaching materials and equipment, the researcher's easy access to the center, and the existence of a living workshop belonging to the laboratory. These conditions allowed data to be collected in a natural environment and under equal conditions.

Throughout the data collection process, the researcher did not intervene in any way, and the timing of the observations was not disclosed to the instructors in advance. The observations were conducted taking into account the science center's activity calendar. Furthermore, the objectivity of the data was evaluated by a TÜBİTAK researcher who specialized in chemistry education and had completed a doctorate.

As a result, the selection of this study group provided an information-rich and appropriate sample for thoroughly understanding the current state of laboratory safety practices in science centers, which was the primary objective of the research.

2.3. Data Collection Tools

In this study, data collection tools were designed to cover every stage of the evaluation process. Three main data collection tools were used in the study:

- Pre-Interview Form for Science Center Instructors Regarding Science Laboratory Applications in Workshops,
- Observation Form for Science Laboratory Applications Conducted at the Science Center,
- Post-Interview Form for Science Center Instructors in Science Laboratory Applications in Workshops.

These three different data collection forms were used in the study. The pre-interview form included 12 structured questions aimed at determining the instructors' initial knowledge and perceptions regarding laboratory safety before the activities. The observation form consisted of 23 criteria designed to document instructors' actual safety practices during the laboratory sessions through naturalistic observation supported by video recordings. The post-interview form contained 23 semi-structured questions that allowed instructors to reflect on their behaviors after the activities and explain the reasons behind their practices.

Although all three forms were developed based on the same laboratory safety framework and focused on instructors' knowledge, behaviors, and responsibilities, they differed in timing, structure, and data type. The pre-interview collected self-reported knowledge prior to the activity, the observation form captured real-time behaviors during the activity, and the post-interview form provided reflective explanations after the activity. Additionally, while the pre-interview form was structured, the observation form was criterion-based, and the post-interview form was semi-structured, offering flexibility for further probing.

These forms were developed by the researcher in accordance with the qualitative data collection approach. The preparation process for each form was carried out in five stages:

1. Needs Assessment: Existing practices and needs related to laboratory safety were examined, and the information to be collected was determined.
2. Form Draft: Criteria, headings, and evaluation criteria were created for each form.
3. Expert Opinion: Feedback was obtained from three experts: a university research assistant, an academic with the title of professor in the field of science education, and an instructor working at a different science center. The content and design were adjusted based on the expert opinions.
4. Pilot Application: The forms were applied to six instructors working at a science center outside the center where the research was conducted; the findings were used to increase the validity and reliability of the forms.
5. Final Revisions: The forms have been finalized based on expert opinions and pilot application results.

During the preparation of the forms, the American Chemical Society (2016a)'s "Guide to Chemical Laboratory Safety in Academic Institutions", the Ministry of National Education (2018)'s science textbooks, and the existing safety procedures at the science center were utilized. These sources collectively address key laboratory safety themes such as hazard identification, use of personal protective equipment, emergency procedures, chemical handling protocols, and safe laboratory behavior.

As a result, these three forms are reliable tools developed to comprehensively assess laboratory safety in science applications conducted at science centers. These tools enable the systematic analysis of instructors' knowledge levels, safety behaviors during application processes, and overall safety culture.

2.4. Data Collection

Data for the study were collected using semi-structured interviews and direct observation methods. During these stages, two scientific activities were observed: the "Ocean Acidification" experiment, which aimed to demonstrate the effects of increased carbon dioxide on seawater pH, and the "Mysterious Structure of Water" experiment, which focused on exploring the physical and chemical properties of water through hands-on activities. These activities were selected because they involve chemical reactions, material manipulation, and hands-on procedures frequently presented in science centers, which makes them relevant for assessing laboratory safety practices.

The process was conducted in three stages: preliminary interview, observation, and final interview.

Table 1. Research schedule.

Steps	Data Collection Tool	Goal	Time
1	Pre-Interview Form	Determine the level of laboratory safety knowledge among instructors	Two hours with each instructor
2	Observation Form	Examine security behaviors during the application process	One hours with each instructor
3	Post-Interview Form	Evaluating awareness and experiences after implementation	Two hours with each instructor

In this study, three different data collection forms were utilized at each stage of the process. The pre-interview form included 12 structured questions focusing on key laboratory safety themes such as hazard identification, the use of personal protective equipment (PPE), emergency procedures, and prior safety training. These questions guided instructors to explain their existing knowledge and perceptions before conducting the activities. The observation form consisted of 23 criteria grouped under categories including PPE compliance, chemical and material handling, risk recognition, student management, and adherence to institutional safety protocols. These criteria enabled the systematic documentation of instructors' actual safety practices during the "Ocean Acidification" and "Mysterious Structure of Water" experiments, supported by naturalistic observation and video recordings. The post-interview form contained 23 semi-structured questions prompting instructors to reflect on their behaviors observed during the activities, articulate the reasons behind their safety decisions, and evaluate their awareness and challenges regarding safe laboratory conduct. Together, these three forms provided comprehensive data aligned with the study's objectives.

Interview forms were documented with audio recordings, while observations were documented through video recordings and note-taking. Each form was developed based on the input of 3 experts and finalized after a pilot application with 6 trainers.

To increase the validity and reliability of the study:

- The interview questions were developed in line with the research objectives and reviewed to ensure content validity.
- Data were collected through semi-structured interviews conducted in natural settings in order to increase credibility.
- All interviews were audio-recorded and transcribed verbatim to ensure dependability.
- The collected data were analyzed systematically, and consistency between the data and interpretations was checked.
- Data were stored securely and preserved to ensure confirmability and transparency of the research process.

This comprehensive process ensured that behaviors related to laboratory safety at the science center were analyzed reliably in terms of accuracy, consistency, and depth.

2.5. Data Analysis

The data obtained in this study were evaluated using qualitative data analysis methods. Interview and observation records were transcribed and examined in detail, and a descriptive analysis approach was followed during the analysis process (Creswell, 2017; Merriam, 2009). This approach allowed the data to be classified and interpreted under themes and categories.

The data analysis process was conducted in five stages: organizing the data, coding, creating themes, interpreting, and presenting the findings. In the coding process, analyses conducted by two independent researchers resulted in a reliability rate of 84% according to the Miles and Huberman (1994) formula, and 93% in the second round of analysis. These values indicate a high level of inter-coder consistency.

The coded data were organized under meaningful themes, and five main themes were identified:

1. General Safety Measures
2. Level of Education
3. Emergency Plan
4. Preparation for Potential Incidents
5. Trainer Roles

Each theme was supported by relevant categories and codes within itself; the findings were illustrated with direct quotations from participant statements. This thematic structure ensured a comprehensive assessment of knowledge, attitudes, and behaviors related to laboratory safety practices.

2.6. Validity and Reliability

Various measures were taken throughout the process to ensure the validity and reliability of the research. In qualitative research, validity refers to the researcher's continuous verification of the accuracy of the findings, while reliability refers to the consistency of the findings across different researchers (Gibbs, 2007; Yıldırım & Şimşek, 2018).

In this context, attention was paid to the principles of internal and external validity and reliability.

For internal validity and reliability, interview and observation data were compared, expert opinions were incorporated, and the themes were re-evaluated by an independent expert. During the coding process, two coders independently analyzed the data in two stages, following the procedures described by Miles and Huberman (1994) and Creswell (2007). In the first cycle, coder agreement was 84%, and in the second cycle it reached 93%. To provide a more robust statistical indicator of inter-coder reliability—defined as the degree of agreement or consistency between coders (Cohen & Swerdlik, 2018)—Cohen's kappa statistic was also calculated, resulting in $\kappa = .82$, which indicates a "substantial agreement" level according to Landis and Koch (1977)'s classification. This confirms that the coding process was highly reliable and consistent across coders.

In terms of external validity and reliability, participants were selected appropriately for the research purpose; the data collection tools, analysis procedures, and implementation steps were detailed thoroughly. Additionally, all research documents, coding tables, and raw forms were securely archived to ensure transparency, traceability, and auditability of the entire research process.

As a result of all these practices, it is believed that the findings of the research are highly accurate, consistent, and reliable.

3. Findings

The purpose of this study is to determine and evaluate the safety level of science laboratory practices conducted at a science center in Türkiye. The study examined the current status of laboratory safety practices and the knowledge and application levels of instructors. During the data collection process, structured and semi-structured interviews were conducted with two instructors; laboratory practices were also monitored using an observation form. This section presents the key findings obtained from the analysis of the interview and observation data, along with comments on these findings.

3.1. General Safety Measures Knowledge Levels and Application Process of Instructors

The General Safety Measures theme, one of the five themes created as a result of data analysis, examines the safety measures taken in laboratory processes under three categories: pre-laboratory, application process, and post-application measures.

Table 2. Categories and codes related to the general safety measures theme.

Categories	**Codes**	**Reviews**
Pre-Laboratory	Control of Chemical Materials, Control of Equipment	*"...I look at the Material Safety Data Sheet (MSDS) for chemicals."* *"...all materials should be checked before each experiment."*
During Application	Information	*"...without taking any action, informing them at the door about all security measures..."*
After Application	Chemical Disposal	*"Place any extra materials in the appropriate boxes..."*

Before the lab session, both instructors emphasized the importance of chemical and equipment checks. Instructor 1 stated that they referred to the Material Safety Data Sheet (MSDS) for chemicals and tested their expiration dates and reaction conditions in advance. Instructor 2 paid attention to physical safety elements such as the placement of chemicals and the selection of appropriate containers. This situation demonstrates that the pre-experiment safety culture was adopted in a way that was both knowledge-based and application-oriented.

During the application, code information stood out. The instructors informed the students about the use of personal protective equipment, laboratory rules, and the correct use of tools and equipment. Instructor 1 provided the information before the experiment, while Instructor 2 did so during the experiment; both approaches ensured a safe and educational laboratory environment.

After the application, both instructors emphasized the need for proper disposal of chemicals. Instructor 1 disposed of the chemicals by separating them according to their types, while Instructor 2 poured the remaining materials back into the relevant containers. These practices demonstrate the adoption of environmentally conscious and safe laboratory management.

In general, the findings show that instructors working in science centers address safety not only as a rule but as part of the teaching process. This creates both a safe working environment and a lasting awareness of safety among students.

3.2. Educational Level of Instructors Working in Science Centers Related to Science Laboratory Applications

The findings related to the second theme identified in the analysis of the collected data, namely Educational Level, are presented in this section. The data obtained from the analysis were evaluated under two categories: subject knowledge and pedagogical knowledge of the instructors.

In terms of subject knowledge, safety protocols and chemical hazard class codes stood out. Instructor 1 verbally informed students about safety rules before the "Ocean Acidification" experiment, emphasizing the use of goggles, aprons, and gloves and the need to avoid direct contact with chemicals. Instructor 2 conveyed similar rules in the "Mysterious Structure of Water" experiment and also used a short video to support the process. Both instructors were careful in explaining safety protocols, but they only provided verbal instructions. The lack of written guidelines may prevent students from learning safety rules more permanently. Therefore, it is recommended that written instructions and emergency procedures be provided to students before the application.

In the applications related to the hazard classes of chemicals, both instructors explained the names and usage forms of the substances they used and warned about correct dosage and separate dropper usage. It was observed that the instructors had sufficient knowledge about the safe use of chemicals and effectively directed the students' attention by using both visual and verbal explanations.

In terms of pedagogical knowledge, classroom layout stood out. Instructor 1 emphasized the advantage of gathering students at a single table, allowing them to observe the entire class and intervene quickly in the event of an accident. Instructor 2, on the other hand, aimed to get students to focus more on the experiments by placing them at separate tables. Both instructors adopted different approaches to create a safe and efficient learning environment. Considering the nature of the experiment, the materials used, and the age level of the students, it can be said that both arrangements are based on rational justifications within their own contexts.

3.3. Emergency Plans by Instructors Working in Science Centers Concerning Science Laboratory Practices

One of the five themes identified through the analysis of the collected data was determined to be an Emergency Plan. Findings related to this theme were evaluated under the category of emergency preparedness and management, with training needs and process management codes standing out.

Interviews with instructors revealed differences in awareness and preparedness levels for emergencies during laboratory applications. Although both instructors informed students about general safety rules prior to the application, it was observed that no systematic training process was conducted for emergency scenarios. Instructor 1 emphasized that both themselves and the students needed more training in the event of possible accidents; they stated that awareness needed to be raised on topics such as appropriate intervention methods for different types of fires, the effective use of personal protective equipment, and the selection of appropriate clothing. They also drew attention to the importance of showing students the exit points and safety equipment in the laboratory, but stated that this information was not provided on the day of the application.

Similarly, Instructor 2 also stated that they did not show the emergency exit points or the location of safety equipment during the experiment. Both instructors explained the properties of the chemical materials used in the experiments, but did not introduce equipment such as fire extinguishers, emergency showers, or first aid supplies. This situation demonstrates the need for systematic emergency information provision in the laboratory environment. Students should be shown the location of the laboratory's exit doors, emergency showers, and first aid supplies before the application, and this information should be supported not only verbally but also visually or in writing.

Process management, the second code defined in the emergency plan, reveals the reflexes of instructors in the face of possible accidents. Instructor 1 stated that they reminded students in advance that the emergency shower could be used in case of chemical contact and that they would notify the relevant unit supervisor if necessary. Instructor 2 stated that they intervened quickly in the event of small spills, ensured that students remained at a safe distance, and issued the necessary warnings immediately.

Both instructors demonstrated a proactive approach to process management, identifying potential risks in advance and taking actions to ensure student safety. However, a more systematic emergency management plan needs to be developed for the laboratory environment, and this plan should be supported by practical training sessions conducted by the instructors. This situation highlights the importance of training programs that go beyond mere knowledge transfer and also strengthen behavioral awareness.

3.4. Preparedness Level of Instructors Working in Science Centers for Potential Incidents Related to Science Laboratory Practices

This section presents findings regarding the preparedness level of instructors working in science centers for potential incidents in science laboratory practices. One of the themes identified through data analysis, “Preparedness for Potential Incidents,” includes two main codes: stress management and risk assessment.

Interviews with instructors were conducted before and after laboratory practices. In pre-laboratory interviews, it was observed that instructors' approaches to stress management were important for safe laboratory practices. Instructor 1 emphasized that the instructor must be physically and psychologically prepared before the experiment in terms of stress management before starting the “ocean acidification” experiment. The instructor stated that factors such as low morale or fatigue could lead to distraction in the laboratory, and therefore constant attention was required during the experiment. They also noted that working standing up in the laboratory environment provided advantages in terms of both safety and ease of movement.

Instructor 2 assessed stress management in terms of inner calm and immediate reactions before the “mysterious structure of water” experiment. He stated that in the event of a possible accident, he would first focus on calming himself down and try to balance his emotional reactions quickly. This approach emphasizes the importance of intervening effectively and in a controlled manner without panicking in the event of a possible incident.

The approaches of both instructors to stress management are complementary in terms of laboratory safety. Instructor 1 focused more on preparation, physical conditions, and awareness, while Instructor 2 concentrated on inner balance and calmness during the incident. When these two approaches are evaluated together, it is seen that they support both the preventive and reactive dimensions of laboratory safety.

Findings related to the second code, risk assessment, were obtained from interviews conducted after the laboratory applications. Instructor 1 has an understanding of risk assessment based on experience and observation. He stated that risks should be anticipated in advance according to the age and skill level of the participants, emphasizing the importance of considering the developmental differences among students. The instructor stressed that potential risks cannot be completely eliminated, but it is possible to intervene immediately in these risks through experience.

Trainer 2 approached risk assessment more from the perspective of enforcing rules and providing constant reminders. He emphasized that occupational health and safety measures should not remain theoretical but should be continuously reinforced in practice. He particularly highlighted the importance of repeating safety warnings related to the materials used during the experiment at the beginning and throughout the experiment.

These findings show that risk assessment in laboratory practices must be carried out holistically, based on both professional experience and observation-based approaches and the implementation of systematic safety rules. Instructor 1's experience-based approach and Instructor 2's rule-based approach offer two different but complementary strategies that support each other in terms of laboratory safety. The combination of these two perspectives contributes significantly to the safe and efficient conduct of laboratory activities carried out in science centers.

3.5. Roles of Instructors Working in Science Centers in Science Laboratory Applications

This section presents findings regarding the roles of instructors working in science centers in science laboratory applications. One of the themes identified through data analysis, "Instructor Roles," comprises three main categories: instructor roles before the laboratory, instructor roles during the laboratory, and instructor roles after the laboratory.

Regarding the instructor role before the laboratory, the code "preparation of a reliable environment" stood out. Instructor 1 emphasized systematic preparations such as arranging materials on trays and placing personal protective equipment on tables before starting the "ocean acidification" experiment. This approach contributes to the laboratory process being carried out in a planned, organized, and safe manner. Instructor 2 emphasized the need to eliminate hazardous elements in the laboratory environment and create a safe atmosphere for students. By focusing on the physical safety of the environment and establishing a sense of security for students before the experiment, both instructors ensured that the laboratory started safely.

During the laboratory session, the "classroom management" code came to the fore in relation to the role of the instructor. Instructor 1 created a safe working environment by ensuring that students wore gloves and providing one-on-one support when necessary. Instructor 2 quickly identified dangerous situations and intervened directly, guiding students in working safely with chemicals. Both instructors reminded students to follow laboratory rules and meticulously monitored the use of protective equipment. These observations highlight the importance of classroom management for laboratory safety.

After the laboratory session, instructor roles were grouped under the "workshop cleaning" code. Instructor 1 ensured hygiene by placing all materials in the dishwasher after the experiment and returning any remaining chemicals to their designated containers. They also replaced the protective covers on the tables and cleaned the surfaces. Instructor 2 took responsibility for general cleaning, washing the dishes, and completely removing any chemical residues. Both instructors took care to maintain hygiene and order after the experiment, ensuring that the laboratory was safe for its next use.

These findings indicate that three stages—pre-laboratory preparation of a safe environment, effective classroom management during the application process, and workshop cleanup after the application—are critical for maintaining laboratory safety in a comprehensive manner. The roles that instructors assume throughout the process not only ensure safety but also enable students to experience scientific process skills in safe conditions.

Table 3. Summary of findings related to the theme of instructor roles.

Laboratory Stage	Approach of Instructor 1	Approach of Instructor 2	Common Points
Pre-Laboratory	Arranging materials on trays, placing personal protective equipment	Eliminating hazardous elements, creating a safe environment	Preparing a safe environment, prioritizing student safety
During the Laboratory	Monitoring glove usage, assisting students when necessary	Responding immediately to hazardous situations, ensuring chemical safety	Effective classroom management, monitoring the use of protective equipment
Post-Laboratory	Place chemicals in appropriate containers, clean surfaces, ensure hygiene	Washing materials, checking for chemical residues, ensuring order	Workshop cleaning, maintaining hygiene and order

4. Discussion and Conclusion

4.1. General Safety Measures Knowledge Levels and Application Process of Instructors

This study was conducted to determine the general safety measures taken by instructors working in science centers during science laboratory applications. The findings were grouped into three main categories: safety measures taken before, during, and after the laboratory session.

Before the laboratory session, it was found to be important for instructors to review the Material Safety Data Sheets (MSDS) of chemical materials to take chemical safety precautions in advance and to perform regular equipment checks in order to create a safe working environment. These practices are consistent with standard safety procedures outlined in the literature (American Chemical Society, 2016b; OSHA, 2011).

During laboratory sessions, practices that enhance safety include instructors informing students about safety rules and personal protective equipment, ensuring students remain at their stations, and explaining the functions of materials used in the experiment. These findings are consistent with studies showing that laboratory safety is related to the effectiveness of the learning process (Hofstein & Lunetta, 2004; Singer et al., 2006).

After the laboratory session, the proper disposal of chemicals reflects the instructors' sustainable safety approach. Separating chemicals according to their reaction states and disposing of them appropriately is a critical practice for environmental and human health (National Research Council, 2011; U.S. Environmental Protection Agency, 2023).

Beyond procedural safety measures, the findings also indicate that instructors perceive laboratory safety as an integral part of their instructional role. This result is consistent with previous studies emphasizing that instructors in informal learning environments often prioritize hands-on safety management and situational awareness over formalized procedures (Falk & Dierking, 2013; Tran & King, 2011). The emphasis on classroom management, continuous supervision, and proactive intervention observed in this study supports the view that instructor roles in science centers extend beyond content delivery to include responsibility for maintaining a safe and supportive learning environment.

Overall, the safety measures implemented by instructors before, during, and after the laboratory were found to be consistent with the standards outlined in the literature. This indicates that instructors working in science centers demonstrate a conscious and systematic approach to laboratory safety.

4.2. Educational Level of Instructors Working in Science Centers Related to Science Laboratory Applications

This study reveals that instructors' subject matter knowledge and pedagogical knowledge play a significant role in ensuring laboratory safety and supporting effective learning in science laboratory applications. The findings indicate that instructors are conscious and proactive in applying safety protocols and addressing the hazard classes of chemicals within the scope of their subject knowledge. Verbal safety instructions provided by instructors were found to be effective in ensuring immediate student safety; however, the absence of written and visual materials supporting these instructions was identified as a factor limiting long-term retention. This finding is consistent with the literature, which emphasizes that safety training supported by written and visual materials enhances students' knowledge levels and safety awareness (Abrahams & Millar, 2008; Hofstein & Lunetta, 2004; Toplis & Allen, 2012).

In addition, the findings suggest that instructors' training should be expanded to include safety-related topics such as emergency procedures and first aid information. While instructors demonstrated a high level of awareness regarding chemical hazard classifications and rapid responses to minor spill incidents—aligning with safe laboratory practices reported in the literature (Cornell University, 2024)—the limited emphasis on emergency preparedness points to a need for more comprehensive safety education.

From a pedagogical perspective, classroom arrangement emerged as an important factor influencing both safety and learning. Instructors' preferences for organizing students at a single table or at separate tables offered different advantages in terms of collaborative learning and individual responsibility. Collaborative arrangements promote knowledge sharing and social interaction (Johnson & Johnson, 1999; Vygotsky, 1978), whereas individual work arrangements support sustained attention and strengthen students' sense of personal safety responsibility (Slavin, 1983). These findings highlight the role of pedagogical decision-making in shaping safe and effective laboratory learning environments.

Overall, the results demonstrate that the effective integration of subject knowledge and pedagogical approaches contributes to students' safe, conscious, and meaningful learning experiences in science laboratories. A comprehensive educational approach supported by written and visual safety materials, and enriched with emergency preparedness and first aid training, is likely to further strengthen laboratory safety culture in science center settings.

4.3. Emergency Plans by Instructors Working in Science Centers Concerning Science Laboratory Practices

This study examined the level of implementation of emergency plans in science laboratory practices conducted at science centers. Based on interviews and observations with instructors, two main codes were identified within this theme: training needs and process management.

The findings indicate that instructors' knowledge and awareness of emergency situations were insufficient in several critical areas. In particular, the lack of systematic introduction of safety equipment—such as fire extinguishers, emergency exit routes, and emergency shower stations—to students was identified as a significant shortcoming in terms of laboratory safety. The literature emphasizes that familiarizing students with emergency exits and safety equipment is a fundamental component of effective laboratory safety practices (Harvard University, 2024; Minnesota University, 2024). Failure to provide this information may lead to inadequate or incorrect responses during potential emergency situations.

Within the scope of the training needs code, the findings highlight the necessity of systematic and comprehensive training programs aimed at improving instructors' emergency preparedness and laboratory safety knowledge. Similar studies have reported that educators require additional training in laboratory management, emergency response, and the safe implementation of experimental activities (Coştu et al., 2005; Çepni et al., 2005). These results suggest that emergency preparedness should be addressed not only through individual experience but also through structured professional development opportunities.

In contrast, findings related to the process management code indicate that instructors demonstrated effective on-site responses during minor emergency situations. Instructors were observed to intervene quickly in incidents such as chemical spills and to continue managing the process while maintaining the use of personal protective equipment. These behaviors reflect the application of practical safety awareness and experiential knowledge in real laboratory settings.

However, despite instructors' demonstrated competence in managing routine safety situations, notable deficiencies remain in terms of written safety guidelines, systematic emergency training, and explicit instruction regarding emergency equipment and procedures. Consistent with previous research, informal science education environments often lack standardized emergency protocols when compared to formal school laboratories (Rennie & Johnston, 2004; Tal et al., 2014). The absence of structured emergency planning may reduce the effectiveness of safety practices in high-risk situations. Therefore, strengthening laboratory safety culture in science centers requires not only individual instructor awareness but also institutional support through written procedures, regular emergency drills, and continuous professional development focused on emergency management.

In conclusion, the findings indicate that emergency planning in science center laboratory practices needs to be more comprehensive and systematic. Expanding continuous safety training programs and implementing regular practical drills for instructors will contribute significantly to improving emergency preparedness and enhancing overall laboratory safety.

4.4. Preparedness Level of Instructors Working in Science Centers for Potential Incidents Related to Science Laboratory Practices

This study aimed to evaluate the preparedness levels of instructors for potential incidents in science laboratory applications conducted at science centers. Findings obtained through interviews and observations were grouped around two main codes in terms of laboratory safety: Stress Management and Risk Assessment.

Findings related to stress management indicate that instructors' physical and emotional readiness plays a decisive role in maintaining safety in the laboratory environment. Being mentally focused and emotionally regulated enables instructors to minimize distractions, respond promptly to unexpected situations, and create a controlled learning atmosphere. While one instructor emphasized the importance of physical preparation and maintaining focus before entering the laboratory, the other highlighted inner calm and rapid response as critical factors. These findings are consistent with the literature, which emphasizes that effective stress and time management strategies in laboratory settings enhance both safety and operational efficiency (Carchman, 2019; Harvard University, 2024; Minnesota University, 2024).

In terms of risk assessment, instructors were found to adopt an approach that combines experiential knowledge with systematic safety considerations. One instructor underscored the importance of conducting risk analyses aligned with students' age and skill levels, whereas the other emphasized strict adherence to occupational health and safety regulations. These results suggest that effective laboratory safety depends on the integration of individual experience-based judgments and institutional safety protocols (Houston University, 2024; Richmond & Nesby-O'Dell, 2024).

Overall, the findings related to instructors' preparedness for potential incidents highlight the complementary roles of stress management and risk assessment in laboratory safety. Consistent with previous research, instructors' emotional regulation, situational awareness, and decision-making abilities were found to directly influence their capacity to respond effectively to unforeseen incidents during laboratory activities (Gess-Newsome et al., 2019). The different yet complementary approaches observed among instructors—one focusing on pre-emptive physical preparation and the other on calmness and rapid intervention—reflect multiple dimensions of safety competence. Previous studies emphasize that effective laboratory safety requires a balance between anticipatory risk assessment and adaptive responses during practice (Kelley & Knowles, 2016).

In conclusion, stress management and risk assessment emerge as fundamental components in strengthening instructors' preparedness for potential incidents in science center laboratories. The findings suggest that a holistic approach to laboratory safety should integrate individual coping strategies with systematic safety practices and professional development programs that address not only technical competencies but also psychological readiness and decision-making skills in high-risk situations.

4.5. Roles of Instructors Working in Science Centers in Science Laboratory Applications

This study aimed to examine the roles assumed by instructors during science laboratory applications conducted at science centers. Data obtained from structured and semi-structured interviews with two instructors, along with observations of laboratory activities, revealed that instructors' roles can be categorized into three main stages: pre-laboratory roles, roles during the laboratory, and post-laboratory roles.

In the pre-laboratory stage, instructors' primary responsibility is to prepare a safe and organized learning environment. This includes arranging experimental materials, checking equipment, and ensuring the availability and appropriate use of personal protective equipment. Such preparation is critical for minimizing potential risks and preventing accidents before laboratory activities begin. Consistent with this finding, the literature emphasizes that pre-laboratory planning and hazard elimination are decisive factors in maintaining laboratory safety (Harvard University, 2024). Organizing the laboratory environment in advance allows instructors to manage the experimental process more effectively and reduces the likelihood of unexpected safety issues.

During laboratory sessions, instructors play a key role in maintaining effective classroom management and continuous safety supervision. Instructors monitor students' behaviors, ensure the correct use of personal protective equipment, and intervene immediately when safety rules are not followed. These proactive and timely interventions are essential for sustaining a safe laboratory environment and preventing potential accidents (Richmond & Nesby-O'Dell, 2024). Previous studies also highlight that constant observation and active guidance by instructors constitute a core component of laboratory safety culture, particularly in hands-on learning environments.

In the post-laboratory stage, instructors' responsibilities focus on maintaining cleanliness, hygiene, and order. This includes the proper cleaning of materials, safe storage of chemicals, and preparation of the laboratory for subsequent use. Such practices support the continuity of safety and reinforce hygiene standards. Studies conducted by the University of Houston (2024) similarly emphasize that post-laboratory cleaning and organization are integral elements of comprehensive laboratory safety practices.

Overall, the findings demonstrate that science center instructors assume multifaceted roles throughout the laboratory process, encompassing preparation before the activity, active supervision during experimentation, and systematic organization after the laboratory session. These results align with previous research indicating that instructors in informal science learning environments function not only as content experts but also as facilitators, safety supervisors, and role models for safe scientific practices (Bevan et al., 2010; Falk & Dierking, 2013). The proactive behaviors observed in this study—such as advance material preparation, continuous monitoring of student safety practices, and prompt intervention in risky situations—underscore the importance of instructor presence in ensuring laboratory safety.

Furthermore, the emphasis placed on post-activity cleaning and material management reflects an often-overlooked dimension of laboratory safety highlighted in the literature. Research suggests that safety culture is reinforced not only during experimental procedures but also through routine practices that model responsibility and care for the laboratory environment (Hofstein & Lunetta, 2004). By actively engaging in cleanup and organization processes, instructors contribute to the sustainability of safe laboratory practices and demonstrate professional responsibility to learners.

In conclusion, the findings indicate that the roles assumed by instructors in science centers during pre-laboratory, laboratory, and post-laboratory stages should be addressed within a holistic framework to ensure laboratory safety. Planned preparation, active guidance during experimentation, and systematic organization after laboratory activities collectively play a critical role in establishing a safe and effective laboratory culture. These findings are consistent with the literature and highlight the need for a comprehensive understanding of instructor responsibilities in supporting laboratory safety.

Based on the identified needs related to emergency preparedness, written safety procedures, and systematic training, this study proposes a laboratory safety training model to support both pre-service and in-service educators working in science centers. One of the main contributions of this research is the development of a training model grounded in empirical findings, offering a practical framework for strengthening safety culture and supporting instructors' roles across all stages of laboratory practice in informal science learning environments.

5. Recommendations

5.1. Recommendations for Research

- Expanding the working group: Since the research was limited to a single science center, comparative studies with different centers could increase the generalizability of the results.
- Working with instructors from different fields: Not limiting the study to science education graduates; including instructors from different disciplines could offer new perspectives.
- Studies on chemical safety management: The safe storage and use of chemicals could be a separate research topic.
- Environmental impact assessments: By examining the environmental effects of the chemicals used, laboratory safety can be addressed in terms of environmental responsibility.

5.2. Recommendations for Educators

- Development of laboratory practical training: Educators should be provided with specialized training to develop practical safety skills; pre- and post-training evaluations should be conducted.
- Monitoring knowledge level: The knowledge development of instructors should be monitored; areas of deficiency should be identified and supported with additional training.
- Emergency plans and training: Plans to be implemented in situations such as fire or chemical spills should be taught, and the preparedness level of instructors should be increased through regular drills.

5.3. Recommendations for Science Center Management

- Preparation of safety instructions: Detailed and guideline-based written instructions regarding laboratory safety should be created.
- Continuity of training: Theoretical and practical safety training for managers and instructors should be conducted regularly.
- Measuring student awareness: Safety awareness tests should be administered to students to evaluate the effectiveness of the training provided.

5.4. Laboratory Safety Training Model Proposal

This model aims to enhance the laboratory safety knowledge and skills of educators working in science centers. It covers both pre-service and in-service training processes and is built on the principles of theoretical knowledge, practical experience, and continuous evaluation. The model integrates interactive and applied learning methods supported by updated content.

Table 4. Laboratory safety training and implementation model.

Stage / Component	Objective	Content	Method / Practice	Evaluation
1. Pre-Service Training (New Educators)	To provide new educators with essential knowledge and skills in laboratory safety	-	-	-
Introductory Seminar (2–3 days)	Understanding the importance of laboratory safety and general rules	Introduction to lab environment, safety rules, emergency procedures, PPE usage	Presentations, videos, case studies	Observation, short quizzes
Interactive Training Workshops (3–4 days)	Reinforcing theoretical knowledge through practice	Chemical/biological hazards, safe working techniques, emergency scenarios	Simulations, group work, role-playing	Practical assessment
Evaluation and Certification (1 day)	Assessing training effectiveness	Written and practical evaluations	Tests, observation	Certificate awarded
2. In-Service Training (Current Educators)	To update educators' knowledge and ensure awareness of new safety protocols	-	-	-
Renewal Seminars (every 6 months)	Providing updated information on safety standards	Current regulations, new equipment, lessons from past incidents	Presentations, discussions, interactive sessions	Surveys, short tests
Practical Workshops (Annually)	Improving hands-on safety skills	Emergency drills, safety inspection management, risk assessment	Simulations, case analysis, teamwork	Performance observation
3. Training Content and Methodology	Integrating theoretical and practical learning	Basic safety rules, emergency procedures, risk management, pedagogical methods	Participant-centered, practical, reflective learning	Ongoing evaluation
4. Evaluation and Feedback	Measuring overall training effectiveness	Pre- and post-tests, open-ended questionnaires, observations, performance review	Data collection, analysis, reporting	Feedback for training improvement

The primary goal of this training model is to strengthen laboratory safety practices in science centers across Türkiye by supporting the professional development of educators and promoting safer learning environments. Through integrated pre-service and in-service training programs, educators are expected to acquire both theoretical knowledge and hands-on experience, thereby fostering a more effective and safety-oriented instructional process. Overall, the proposed model aims to establish a comprehensive and sustainable training framework that systematically enhances laboratory safety in science centers.

Compliance with Ethical Standards

The study protocol was approved by Gazi University Ethics Committee with the decision number E993857 on 11.07.2024.

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Conflict of Interest

The authors have no conflict of interest to declare.

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