ECLÉTICA QUÍMICA

Eclet. Quim. 49 | e-1504, 2024

Original Article, Education in Chemistry and Correlated Areas

https://doi.org/10.26850/1678-4618.eq.v49.2024.e1504

The concept of chemistry laboratory in high school

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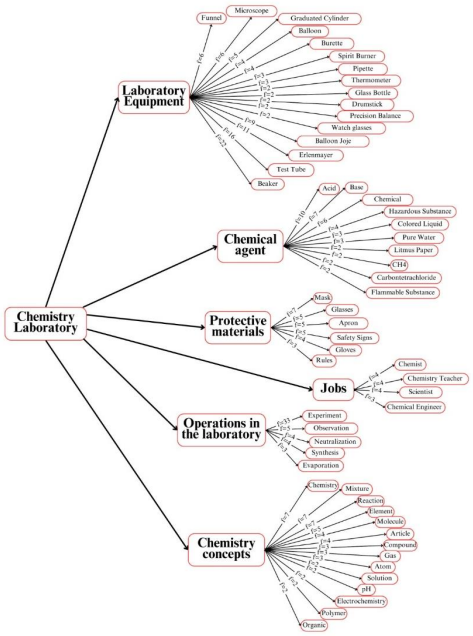
Abstract

This research aims to determine the cognitive structures of high school students in the "chemistry laboratory" and to reveal their alternative concepts using the independent word association test and the drawing-writing technique. The sample of the study consists of 60 high school students. Content analysis was used to evaluate the data obtained from the sample group. The codes from the data were brought together and categories were created. In the analysis of the data, sentences and drawings obtained from the writing and drawing techniques were also evaluated separately. When students' answer words are analyzed, it is seen that the concepts related to chemistry laboratory are Laboratory equipment (f:99), Chemical agent (f:41), Protective materials (f:29), Jobs (f:15), Operations in the laboratory (f:49) and Chemistry concepts (f:53). It was determined that the cognitive structures of high school students towards the concept of chemistry laboratory were related to laboratory equipment, chemical agent, protective materials, jobs, operations in the laboratory, chemistry concepts named six categories.



Article History

Received July 17, 2023
Accepted September 03, 2024
Published December 29, 2024

Keywords

1. chemistry laboratory;
2. high school students;
3. word association test;
4. cognitive structures;
5. chemistry.

Section Editors

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Highlights

- Definition of the chemistry laboratory as an area of discovery.
- The laboratory is important for chemistry.
- Chemistry laboratories foster safety awareness.

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1. Introduction

Experimental applications in science are closely related to practical studies, namely laboratories (Gray, 2014). It is known by everyone that laboratories are a natural feature of school science (Wei and Liu 2018; Wellington and Ireson 2012). It would be more effective to describe the relationship of laboratories with science at school as follows, just as cooking belongs to the kitchen or gardening belongs to the garden, science learning manifests itself with metaphors that it belongs to the science laboratory (Hofstein *et al.*, 2013).

It is also accepted by many authors in the literature that laboratory teaching, in which students experiment in the laboratory, is the most basic and essential component of science courses (Hofstein and Lunetta, 1982; Hofstein and Lunetta, 2004; Johnstone and Al-Shuaili, 2001; Reid and Shah, 2007; White, 1996). Improving students' understanding of science, understanding the nature of science, creating scientific events in the mind, practical skills, problem solving, interest and motivation are reported as the goals of laboratory teaching (Hofstein and Lunetta, 2004).

In the studies aimed at the objectives of the chemistry laboratory, for example, the objectives of the general chemistry laboratory such as being interested in science, having laboratory techniques and skills, developing critical thinking skills, establishing a connection between the course content and the laboratory, and creating collaborative group work skills are revealed (Bruck *et al.*, 2010). The goals of the chemistry laboratory are seen as the realization of meaningful learning by focusing on cognitive, affective and psychomotor areas. Bretz *et al.* (2013) examined cognitive, affective and psychomotor goals in detail in their study. Cognitive goals are thought to be establishing a connection between the course and laboratory work, establishing a connection between the laboratory and daily life, emphasizing the laboratory and providing conceptual understanding, linking the laboratory content between mathematics and other sciences, and adapting critical analysis. Affective goals included establishing relationships between the real world and the laboratory, developing the ability to work independently and collaborating. Among the psychomotor goals are learning to use laboratory equipment and laboratory techniques.

Experimenting in the laboratory is related to the goals set in the affective field. For example, finishing the experiment quickly and late, or getting good grades from the test result or making a mistake and sharing it with the lecturer (DeKorver and Towns, 2015). It has been determined that students follow some steps without thinking or understanding while doing experiments in the laboratory. It has been revealed that students have difficulties in self-control in laboratory lessons. As a result, it is not possible to establish a connection between the operations performed in the experiment and theoretical knowledge. Students only focus on experimental procedures and aim to finish the experiment without understanding it (Galloway and Bretz, 2016). In developing students' reasoning and argumentation levels, it is very important to think deeply about the evidence obtained from experiments and to realize how to use the experimental results. For this reason, it is of great importance to conduct experiments in chemistry lessons at all levels of education (Uzuntiryaki-Kondakci *et al.*, 2021). Laboratory applications and task-based activities enable students to develop different skills such as self-assessment (Wu *et al.*, 2023). Starting from teacher candidates, teachers should focus on the importance of chemistry and teaching intellectual processes to ensure sustainability. Teachers trained in this subject can ensure that their students in their classes go through the same process (Delaney *et al.*, 2021). Focusing on student-centered practices in chemistry teaching not only increases students' academic success, but also increases their belief that they can manage their own learning process and improves their motivation (Cascolan, 2023). The knowledge that students have about the laboratory also sheds light on how laboratory teaching should be planned. The selection of materials used in daily life is very important in experiments to be carried out in the laboratory (Hakim *et al.*, 2022). Reconciling chemistry with daily life positively affects students' participation and motivation in class (Mustafaoğlu and Yücel, 2022a). Determining students' concepts about the laboratory actually reveals what they know and do not know about chemistry subjects. In this way, it is clarified what to do when planning the lecture, what difficulties to choose when choosing experiments on the subject, and what to pay attention to regarding safety when conducting experiments (Triayuni *et al.*, 2023). The knowledge level of high school students about chemistry and chemicals is revealed very effectively with the word association test. Students have a lot of fun while using this application, and it also enables them to write realistic expressions (Alkan *et al.*, 2021). Based on these laboratory data, it is necessary to determine the cognitive structures of the students for the chemistry laboratory. This research was carried out to determine the cognitive structures of high school students about "chemistry laboratory" and to reveal their alternative concepts by using the independent word association test and the drawing-writing technique. In this way, the cognitive structures of the students for the chemistry laboratory will be determined and the points to be considered in laboratory teaching will be emphasized.

2. Experimental

2.1. Research design

Phenomenological methods explain the phenomena that are known but do not have a detailed understanding. In this study, the phenomenography method, one of the qualitative research methods, was used. We cannot think that we fully comprehend the phenomena such as events, experiences, perceptions and concepts that we encounter in various forms in our lives. The phenomenology method is used to investigate the phenomena whose meaning we cannot fully comprehend (Yıldırım and Şimşek, 2006). In this study, the cognitive structures of high school students regarding the concept of chemistry laboratory was examined with the independent word association test.

2.2. Participants

The sample of the study consists of 60 high school students studying in Turkey. The sample of the study was determined by a purposive sampling method. Purposive sampling is a widely used technique in qualitative research. This technique is preferred in identifying and selecting rich situations to use limited resources effectively (Patton, 2002). Purposeful sampling is a sample selection method used to select samples depending on the purposes of the research to be conducted (Fraenkel *et al.*, 2012). High school students who took chemistry courses in high school were included in the sample group. Students were informed about the study. Participant consent was obtained from the students who wanted to participate in the study. Initially, the study started with 72 high school students. Twelve students (n=12) were excluded from the study because they did not continue later. High school students filled out a voluntary participation form before participating in the

research. Table 1 shows the demographic information of the research sample group.

Table 1. Demographic details and characteristics of sampling.

Categories		f	%
Gender	Female	26	43.3
	Male	34	56.7
Grade	9th class	5	8.33
	10th class	6	10
	11th class	6	10
	12th class	43	71.7
Total		**60**	**100**

The sample of the study consists of 60 high school students. 26 females (43.3%), 34 males (56.7%). The distribution of students by grades is 5 students in 9th grade, 6 students in 10th grade, 6 students in 11th grade and 43 students in 12th grade.

2.3. Instrumentation

The word association test (WAT) was used as a data collection tool in the research. It was aimed to collect detailed data in order to reveal the cognitive structure of the sample group regarding the concept of "chemistry laboratory". While applying for the word association test, the points that the students would probably have difficulty were explained. In addition, sufficient time was given to the students. The word association test was administered to 72 high school students. Of these, 60 were evaluated. While evaluating the obtained data; first the concepts that come to mind of the students about the concept of "chemistry laboratory" were categorized and the counting method was used. Figure 1 shows the word association test.

Dear students,
This survey is conducted to determine which concepts you associate with each other regarding the chemistry laboratory. Please write the words you think are related to the concepts in the spaces opposite the following concepts. Continue this process quickly until you have no more words to write. It is not a problem if you cannot fill in all the blanks. Thank you for your time. No personal information was requested.

Chemistry laboratory .....
Chemistry laboratory .....
Chemistry laboratory .....
Chemistry laboratory .....
Chemistry laboratory .....
Chemistry laboratory .....
Chemistry laboratory .....
Chemistry laboratory .....
Chemistry laboratory .....
Chemistry laboratory .....

Make a sentence with the words you wrote above:

Tell us what you know about chemistry laboratory in 5 minutes?

Figure 1. Word association test for chemistry laboratory keyword.

2.4. Data analysis

As a result of the word association test, the evaluation of the data obtained from the sample group for the key concept of "chemistry laboratory" was carried out with the content analysis method. Categories were created by establishing a relationship between the answer words for the chemistry laboratory, which is the key concept. Words that are repeated only once and that are not relevant were not taken into consideration. The answer words of the students were first examined by the researchers within the framework of relevance to the subject, and some of them were excluded. In the content analysis, the frequencies of the words in the categories were also calculated. Sentences and drawings obtained from the writing and drawing techniques of the word association test were also analyzed. Answer words, writing and drawing technique data analysis and students' views on the key concept were examined in depth (Rennie and Jarvis, 1995). The results were analyzed by considering the categories created according to the key concept. Content analysis is done to reach the concepts that will explain the data and to reveal the relationships between these concepts (Yıldırım and Şimşek, 2006). First of all, the data should be divided into categories, upper and lower classifications should be made and supported with numerical data (Sönmez and Alacapınar, 2011). Then, the codes emerging from the data are brought together and categories are created (Cresswell, 2018). In the analysis of the data obtained from WAT, the number of repeated words is examined in the first place, then the connection between the words is created. For this, the semantic relationship technique is used (Atasoy, 2004).

3. Results and discussion

3.1. Findings obtained from the Word Association test

In the study, high school students' perceptions of the chemistry laboratory were examined with the word association test. According to WAT, 302 answer words were collected from 60 students. In the data analysis, 16 words (5.30%) were excluded due to reasons such as not being relevant or being repeated once (Kostova and Radoynovska, 2010; Kurt, 2013). 286 answer words were examined, it was determined that they consisted of 55 repetitive words and were grouped under 6 categories. Table 2 provides details.

Table 2. Distribution of cognitive structure obtained by the word association test related to the concept of "chemistry laboratory" by categories.

Categories	Concepts and frequencies		f
Laboratory equipment	Beaker (22)	Burette (4)	99
	Test Tube (16)	Spirit burner (3)	
	Erlenmayer (11)	Pipette (3)	
	Balloon Joje (9)	Thermometer (2)	
	Funnel (6)	Glass Bottle (2)	
	Microscope (6)	Drumstick (2)	
	Graduated Cylinder (5)	Precision Balance (2)	
	Balloon (4)	Watch glasses (2)	
Chemical agent	Acid (10)	pure water (3)	41
	Base (7)	litmus paper (2)	
	Chemical (6)	CH4 (2)	
	Hazardous substance (4)	Carbontetrachloride (2)	
	Colored liquid (3)	flammable substance (2)	
Protective materials	Mask (7)	Safety signs (5)	29
	Glasses (5)	Gloves (4)	
	Apron (5)	Rules (3)	
Jobs	Chemist (4)	scientist (4)	15
	Chemistry teacher (4)	chemical engineer (3)	
Operations in the laboratory	Experiment (33)	Synthesis (4)	49
	Observation (5)	Evaporation (3)	
	Neutralization (4)		
Chemistry concepts	Chemistry (7)	Gas (3)	53
	Mixture (7)	Atom (3)	
	Reaction (7)	Solution (2)	
	Element (5)	pH (2)	
	molecule (4)	Electrochemistry (2)	
	Article (4)	Polymer (2)	
	Compound (3)	Organic (2)	
Total	**55 words**		**286**

The first category is the "Laboratory equipment" category. The frequency of this category, which consists of 16 answer words, is 99. In the category of laboratory equipment, students are Beaker (22), test tube (16), Erlenmayer (11), balloon Joje (9), funnel (6), microscope (6), graduated cylinder (5), glass balloon (4), burette (4), spirit cooker (3), pipette (3), thermometer (2), glass bottle (2), baguette (2), precision balance (2), and watch glass (2).

The second category is "Chemical agent" and the frequency of 10 answer words is 41. In the chemical agent category, acid (10), base (7), chemical (6), hazardous substance (4), colored liquid (3), pure water (3), Litmus paper (2), CH_4 (2), carbon tetrachloride (2), flammable substance (2).

The third category "Protective materials" is represented by 6 answer words and its frequency is 29. Answer words; mask (7), goggles (5), apron (5), safety signs (5), gloves (4), rules (3).

The fourth category "Jobs" is 15 in frequency with 4 answer words. In this category chemist (4), chemistry teacher (4), scientist (4), chemical engineer (3)

The fifth category, "Operations in the laboratory", consists of 5 answer words, while the frequency is 49. In this category, experiment (33), observation (5), neutralization (4), synthesis (4), evaporation (3) are seen as the answer words.

The sixth and final category is "Chemistry concepts" The frequency of 14 response words is 53. Sixth category chemistry (7), mixture (7), reaction (7), element (5), molecule (4), substance (4), compound (3), gas (3), atom (3), solution (2), pH (2), electrochemistry (2), polymer (2), organic (2).

In order to better understand the cognitive structure model that emerged based on the findings obtained as a result of the word correlation test related to the chemistry laboratory concept of the students, the categories and the words representing the category were created by creating a figure. Cognitive structure model was shown in **Fig. 2**.

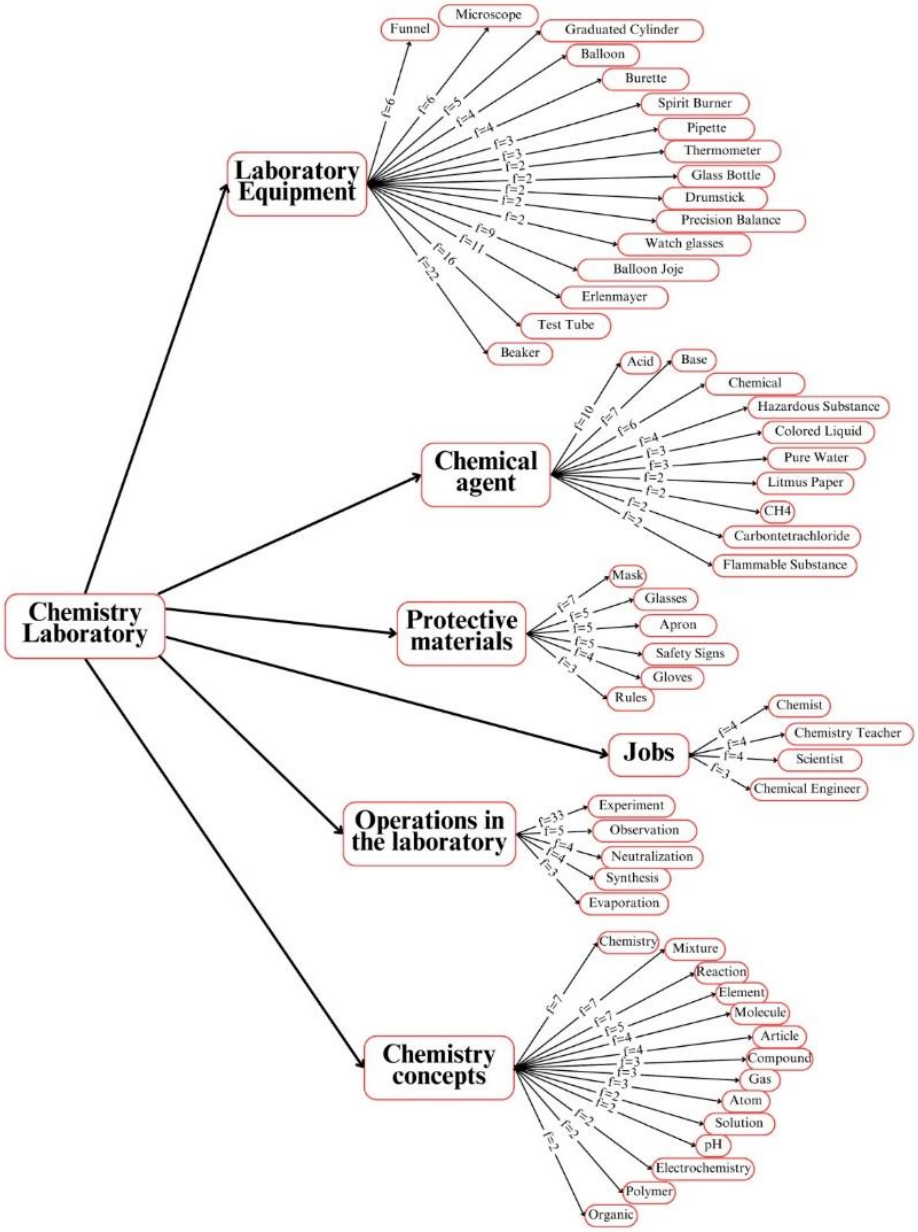


Figure 2. Cognitive structure for the concept of chemistry laboratory.

3.2. Findings from the writing-drawing technique

Students were asked to form sentences at the end of the word association test for the concept of chemistry laboratory. In WAT, students' writing technique sentences were also evaluated. The frequencies of the sentences written by the students were analyzed in the determined categories. In **Table 3**, the frequencies of the sentences written by the students for the concept of chemistry laboratory are given.

Table 3. WAT writing technique distribution of sentences by categories and frequencies.

Categories	f
Laboratory equipment	16
Chemical agent	2
Protective materials	10
Jobs	3
Operations in the laboratory	19
Chemistry concepts	10
Total	**60**

When the table is examined, it is seen that the highest frequency value is in the category of "operations performed in the laboratory" (f: 19). Examples of sentences belonging to this category are given below. Next to the sentence examples, the numbers represent the codes given to the students.

S29: Acid, the amounts of which we determined with the help of graduated cylinder, and with the help of some of our chemistry teachers, we reacted in a glass container so that salt and water were released. This reaction is called the neutralization process.

S23: New substances are synthesized as a result of the reaction that takes place in the beaker with acid and base.

S24: Acids and bases react chemically to form salt and water.

S17: In the neutralization reaction, acid and base react to form water and salt water, which is an ionic compound.

The second-high frequency value is in the category of "Laboratory materials" (f: 16). Examples of sentences for this category are as follows.

S5: Materials such as beaker, flask, test tube, separating funnel, graduated cylinder are indispensable materials for experimentation in the chemistry laboratory.
S9: These instruments, which are sensitive glasses, are used for experimentation. For example, a straw is used to transfer a substance from one container to another container.
S25: We used a separating funnel to separate the liquids that we mixed accidentally.
S56: Beaker is used in some evaporation reactions.

It is seen that the frequency value of the "Protective materials" category is (f: 10). Below are examples of sentences that describe this category.
S47: We conducted experiments on acids and bases in the chemistry laboratory and learned information about flammable and combustible materials.
S45: We should be careful while doing experiments.
S28: When we are going to do an experiment in the laboratory; we must obey the laboratory rules by wearing glasses, gloves and aprons.
S7: Protective materials such as goggles, masks, etc.

While the frequency value of the category "Chemistry concepts" is (f: 6), examples of sentences explaining this category are below.
S34: Chemistry from alchemy; examines the structure and properties of atoms, elements or compounds.
S46: Organic is a difficult subject.
S57: I wrote the first words that came to my mind and these words explain chemistry to me. In chemistry, if there is no matter or element, there can be no combination, and without it, experiments cannot be done, and new information cannot be reached.

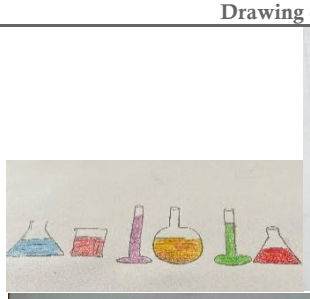
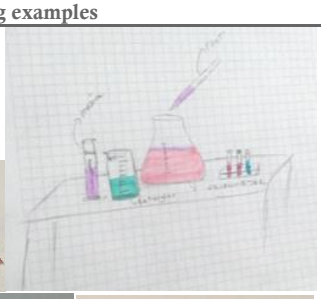
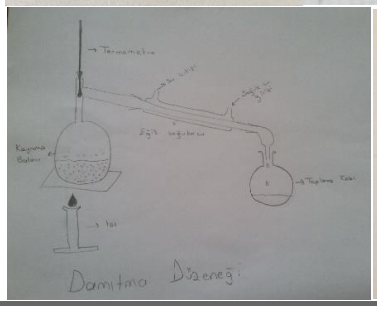
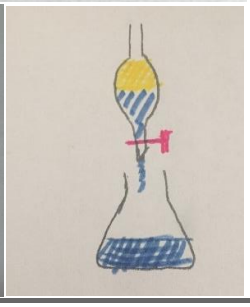
While the frequency value of the "Occupations" category is (f: 3), examples of sentences explaining this category are below.
S55: When I say a science laboratory, I think of it as being free. People working in the laboratory need to be passionate and passionate about their work. After all, you may fail because of an experiment you've been working on for years, and you have to be excited for science to continue.
S33: The chemist did an experiment using gloves, beakers and microscope.

While the frequency value of the "Chemicals" category is (f: 2), examples of sentences explaining this category are below.
S13: There may be abrasive substances in homogeneous mixtures placed in capsules in chemistry experiments.
S41: The list of words that come to mind when I think of the laboratory are chemicals.

3.3. Findings obtained by drawing-writing technique

Students made 57 drawings in the word association test. Eight of them were not included in the study due to reasons such as not being related to the subject, and the drawings made by 49 students were examined according to categories. The findings obtained are summarized in **Table 4**.

Table 4. Distribution of results obtained by drawing technique related to the concept of chemistry laboratory according to categories frequencies and drawing examples.

Categories	Drawing (f)	Drawing examples
Equipment and materials	22	 
The experimental setup	27	 

When Table 4 is examined, it is noted that the category with the highest frequency in student drawings is the experimental setup category (f:27), while the second place is the category of tools-equipment and materials (f:22). Categories and drawing examples are also included in the table.

This research was conducted to reveal the cognitive structures of high school students regarding the concept of "chemistry laboratory" through the independent word association test. When WAT answer words are examined, it is noticed that the variety of concepts is high (f:286). When the answer words of the students were analyzed, it was determined that the concepts related to the chemistry laboratory were gathered in 6 categories: Laboratory equipment, chemical agent, protective materials, jobs, operations in the laboratory, and chemistry concepts. It is the category of "laboratory equipment" with the highest frequency (f: 99). The frequency of the chemical agent category is 41. The protective materials category is 29, the Jobs category is 15, the operations in the laboratory category is 49, and the chemistry concepts category is 53.

Chemistry is an experimental science. Experimentation is the most important requirement to become an expert in this field. It is unacceptable that traditional laboratory programs have too little content to provide training for the development of this skill (Pickering, 1984). In chemistry, experiments carried out in the

laboratory and the results obtained should be an important component of course evaluation, otherwise failure will occur (Wilson, 1987). Traditional teaching produces learning characterized by superficial and superficial memorization. Students do not forget very little of what they have learned, and they have difficulty in applying this information they have not forgotten (Saint-Jean, 1994).

Chemistry, which is described as a difficult science among young people, is also seen as challenging, difficult and boring. The reason for this belief, which is accepted by the students, may be abstract topics such as the structure of the atom or chemical bonds in chemistry. It is difficult to visualize how these issues came to be. Elimination of this prejudice of students about chemistry will be possible with laboratory practices and activities (Mujtaba *et al.*, 2020; Rüschenpöhler and Markic, 2020). Chemistry laboratory practices should be used to emphasize the experimental nature of chemistry (Wilson, 1987). For this reason, the concept of chemistry laboratory has great importance at every level of education.

Teaching multiple representations can be used to develop the cognitive structure of chemistry (Derman and Ebenezer, 2020). Molecular geometry, chemical calculation and reaction balancing are seen as the most difficult topics (Fitriyana *et al.*, 2023). Revealing the relationship between chemistry and daily life in the high school chemistry curriculum will make it easier for teachers to teach the lesson (Mustafaoğlu and Yücel, 2022b) and will support students in reducing their prejudices and concerns about chemistry (Altundağ and Yücel, 2022). Before starting a chemistry course in high school, students' perceptions of chemistry should be determined and course contents should be arranged according to these perceptions (Altundağ *et al.*, 2022). With appropriate teaching methods, it was determined that there was an increase in the number of response words and the connections between them in the word association test on a specific subject such as saponification (Baptista, 2019). In terms of chemistry laboratory concepts, the most repeated category by students is the materials used in the laboratory. Next come the concepts of chemistry and operations in the laboratory. From this point of view, it is revealed that laboratory-related applications should be given more space while planning the chemistry curriculum.

4. Conclusions

The research shows that 286 meaningful words obtained from sixty students are interested in the chemistry laboratory of high school students. By benefiting from this interest, chemistry laboratory applications should be given more place for students to love and understand chemistry. Especially high school level is an education level where prejudices can be eliminated before starting university education. In high school, students should do more experiments in the lessons and enter the chemistry laboratory. In this way, meaningful learning will be realized by realizing the concrete applications of the abstract concepts of chemistry.

Data availability statement

The data will be available upon request.

Funding

Not applicable.

Acknowledgments

I would like to thank all the students who volunteered to contribute to the data collection process for the research.

Conflict of interest

The authors declare that there is no conflict of interest.

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