Master Thesis

Students' Experiences in Learning Chemistry at Secondary Schools in Azerbaijan

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STATEMENT OF AUTHENTICITY

I have read ADA University's policy on plagiarism and academic integrity. I confirm that this thesis, namely (Students’ Experiences in Learning Chemistry at Secondary Schools in Azerbaijan) is my own work. All sources used in this thesis have been properly acknowledged and referenced.

I also declare that this thesis has not been submitted for any other degree, diploma, or academic qualification at ADA University or any other institution.

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ABSTRACT

This qualitative study explores how secondary school students experience learning chemistry subject at schools in Baku, Azerbaijan, precisely focusing on the 7th and 8th-grade students. Semi-structured interviews with 16 students and 6 teachers from both public and private schools revealed that students initially perceive chemistry as a “conceptual struggle” because of the abstract disconnection between macroscopic phenomena and symbolic representations, moreover, findings were analyzed in terms of the student engagement framework (Bond et al., 2020), showing that involvement is shaped by three distinct domains: behavioral (driven by laboratory participation, asking questions, and note-taking), affective (influenced by teacher personality, gamified joy, and peer collaboration as emotional support), and cognitive (facilitated by real-world links and everyday metaphors). Additionally, this study also identifies a concept namely “Parallel Learning System”, which happened through factors like AI-assisted explanations, family support, and independent homework that students use to construct meaningful understanding outside the classroom, in order to compensate the challenges of the formal curriculum. Despite the positive drivers for engagement in chemistry learning, a significant gap exists between the national curriculum and actual practice of students, where public school students often remain passive observers during laboratory lessons due to resource constraints. Furthermore, environmental barriers like classroom noise and psychological factors like “chemophobia” significantly diminish affective involvement of students in chemistry lessons. Consequently, this thesis emphasizes the importance of instructional scaffolding and the use of “bridge talk” to help students navigate through Johnstone’s Triangle concept to mitigate fear of chemistry subject, and improve overall scientific literacy.

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CHAPTER 1: INTRODUCTION

Chemistry subject at lower secondary education (grades 7th and 8th) is considered an integral part of schooling, recognized internationally in ISCED (International Standard Classification of Education) Level 2 (UNESCO Institute for Statistics, 2015; UNESCO Institute for Statistics, 2021). In Azerbaijan, national reforms emphasize competency-based outcomes in science that include modeling, experiments, simulations, animations, and real-life applications, to enhance and strengthen students' learning in chemistry (Ministry of Science and Education & Institute of Education, 2023). Besides curriculum refinement, the SEC (State Examination Center) has set a program that includes general, organic, and inorganic chemistry and assessment that prioritizes symbolic reasoning and problem-solving (State Examination Center, 2025).

However, recent data from the State Examination Center's admission exams of students indicates that the average percentage of correct answers in chemistry was 24.18% for Group I (applicants who are enrolling to engineering and science-oriented (technical subjects) programs), and 49.17% for Group IV (applicants who are enrolling to medical, health-related programs), showing lowest results in Group I and moderate results for Group IV compared with results of other science subjects like physics and biology (State Examination Center, 2025, table 1.26, p. 64). In addition, recent certification exams of whole teachers in Azerbaijan revealed that only 17 teachers achieved maximum score, where there is no chemistry teachers, which experts explain not as individual weakness of teachers but as structural constraints such as limited laboratory provision, uneven chemistry-specific preparation resources, and adaptation challenges that are faced by teachers and schools in relation to technology-based testing that itself reflects students' daily experiences of learning chemistry (Aliyeva, 2025). This context displays a persistent intention-experience gap: while policy expects inquiry, practical work, and modeling in the chemistry subject, many learners still struggle to coordinate among macroscopic phenomena, submicroscopic particles, and symbolic language - the classic Johnstone's triangle challenge (Johnstone, 1982). Taking into consideration that students' learning now extends across the classroom, homework/tutoring, and online spaces, and that benefits from digital tools or virtual labs depend on explicit "bridge talk" and debriefs linking macro- and submicro-symbols, this study explores how students describe their experiences of learning chemistry across diverse learning contexts. Specifically, this study examines chemistry lessons at schools, homework and tutoring practices, and online learning, as well as the resources and instructional practices that students perceive as supporting or hindering their understanding of the chemistry subject. The findings of this research can be used for possible improvements of the chemistry curriculum by stakeholders and may help teachers in organizing their lesson plans in the chemistry subject in Azerbaijan.

1.1 Purpose and Significance of the Study

My purpose in this study is to explore students' learning experiences in chemistry class and what factors contribute to their engagement with this subject. Since students' own perceptions of what helps or hinders them in learning chemistry have not been systematically documented in Azerbaijan, this study will contribute student-voice evidence and provide concrete supports that teachers can adopt (e.g., implementing inquiry-based and project-based learning, practical/virtual labs, structured diagrams). Moreover, taking into consideration that the national chemistry curriculum emphasizes competency-based learning with modeling, experiments, simulations, and real-life applications (Ministry of Science and Education & Institute of Education, 2023), and the State Examination Center's (SEC) analyses highlight strong symbolic and representational demands in chemistry (State Examination Center, 2025), it is significant to research students' experiences in chemistry learning at lower-secondary education and key findings of this research will give the way for further researches in this field. Considering that in Azerbaijan there is a limited study about the challenges of students in chemistry learning, the findings will contribute to the existing literature about teaching and learning chemistry research and will help educators and policymakers to improve chemistry teaching and curriculum in Azerbaijan.

1.2 Research Questions

1. How do students at secondary schools in Azerbaijan describe their experiences of learning chemistry?
2. What factors contribute to student engagement in chemistry classes?

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter will explore how secondary school students experience learning chemistry and which factors contribute to students' engagement in learning this subject across school lessons, homework/online tutoring, and online/media. This chapter indicates a synthesized view on how students' challenges in chemistry learning have been investigated across Azerbaijan, post-Soviet countries, and in different international settings, including Europe and East Asia. Priority is given to research from the last five to six years, additionally using classical theories, and Azerbaijan's policy documents that present intended learning experiences (inquiry, practical/virtual labs, modeling, simulations/animations, and real-life applications) (Ministry of Science and Education of the Republic of Azerbaijan, 2023). This analytical framework, linking recent post-2020 research with the intended practices demonstrated in Azerbaijan's chemistry curriculum, allows deep, critical comparison between what should happen and what students say actually happens while they learn chemistry.

2.2 Definition of Terms

Students' experiences - for this study, this term is defined as what students do, feel, and learn in chemistry, including the resources and practices that students perceive as shaping their participation (Taber, 2013).

Student engagement is defined as a student's behavioral, cognitive, and affective involvement in the lessons; it is framed not only by lesson quality but also by learner-related factors, like prior knowledge, motivation, and self-regulation, as well as social and contextual influences (Bond et al., 2020). The term "representational competence" refers to a student's ability to interpret, translate, and coordinate diverse forms of chemical representations, such as macroscopic observations, submicroscopic particle models, and symbolic representations. This concept of representations is Johnstone's classical model of interpreting chemistry knowledge that describes three levels of processing chemical knowledge: macroscopic level (what students see), submicroscopic level (how students assume atomic-molecular models), and symbolic level (writing formulas/equations) (Johnstone, 1982, pp. 377-379). The term "lower-secondary level" in this research means formal education in 7th and 8th grades at schools that demonstrate Level 2 of the International Standard Classification of Education System (UNESCO Institute for Statistics, 2015; UNESCO Institute for Statistics, 2021).

2.3 Positioning of Chemistry within Lower-Secondary Science Education

Lower-secondary chemistry is widely positioned as a foundation for scientific literacy and later STEM study, incorporating international assessment and frameworks that target this stage for core competencies and conceptual understanding (Organization for Economic Co-operation and Development (OECD), 2016). Research depicts that students' conceptual understanding enhances when the given instructions help them to coordinate macro phenomena, submicroscopic models (representation of matter at the atomic-molecular level), and symbolic language (Johnstone, 1991). At the same time, recent syntheses of research demonstrate positive effects for guided inquiry/practical work when tasks are clearly scaffolded toward explicit goals of concept and explanation (Urdanivia Alarcón et al., 2023; Sam, 2024). The research about integration of virtual and remote laboratories (VRLs) in chemistry classes reveals that creating environment with the access for students to use virtual, remote laboratories is able to successfully foster positive learning outcomes and include robust communication tools, while a critical gap remains in the integration of automated guidance and regulation features necessary to optimize effective student collaboration (Rosli & Ishak, 2024; Kurtz et al., 2025). Moreover, the research on virtual laboratories indicated that virtual chemistry laboratories are useful and extra helping "tools" to real laboratories (Chan et al., 2021). In addition, the investigation about the usage of authentic tasks and socioscientific issues (SSIs) explicitly identified that chemistry subject as one of the primary subjects (accounting for 34% of the analyzed articles) that has most successfully integrated socioscientific issues, these context-based learning environments promotes a better understanding of chemistry subject and assist students in connecting chemistry subject to their everyday life, highlighting a chemistry-specific topics like energy and resources, sustainable development, and waste control (Viehmann et al., 2024).

The chemistry curriculum in Azerbaijan for grades VII-XI demonstrates competency-based outcomes emphasizing research skills, modeling, and the use of virtual/digital experiments to connect macro-submicro-symbolic representations that align with previously given post-2020 research evidence (Ministry of Science and Education of the Republic of Azerbaijan & Institute of Education, 2023). What is not deeply researched is how established competence-based outcomes for chemistry curriculum are experienced by students in everyday lessons, homework, tutoring, and online/digital study, precisely, students' voices on experiencing it.

Recent curriculum reforms also put forward the inquiry practices, modeling, and representational in lower-secondary science, for example, Australia's Version 9 curriculum (Years 7–10), Germany's 2024 KMK standards for chemistry follow the same type of outcomes, namely inquiry practices, modelling, and research skills, as in the Australia's Version 9 curriculum (ACARA, 2022; Kultusministerkonferenz, 2024).

In short, the intentions of Azerbaijan in the chemistry curriculum reflect research-supported directions like representations, guided inquiry, productive use of virtual labs, and relevance. The critical gap and the focus of this study is to examine students' perspectives on these given intended outcomes, to explore what actually helps or hinders their understanding and engagement in chemistry lessons at the secondary level. The next sections, therefore, will demonstrate empirical studies on chemistry learning experiences with attention to their experiences in the classroom, during homework tasks, tutoring, and online study.

2.4 Students' Experiences in Chemistry Across Settings

2.4.1 Classroom lessons

Students from diverse countries report that the chemistry subject seems abstract and difficult to construct an understanding without assistance in connecting macroscopic, submicroscopic, and symbolic levels (Johnstone, 1991; Salonen et al., 2018; Taber, 2013). Targeted instructional supports, such as explicit translation between macroscopic, submicroscopic, and symbolic representations, guided simulations, and teacher talk that links particle-level models to equations have been shown to reduce students' difficulties in understanding chemistry and strengthen conceptual comprehension (Johnstone, 1991, 2000; Talanquer, 2022; Akesson Nilsson & Adbo, 2024). For example, Bulgaria, to reduce the challenges in students in understanding chemistry shifts from traditional rote memorization in chemistry toward a competency-based approach that utilizes problem-based learning, experimental work, and project-based activities to boost student motivation, and a significant focus in studying chemistry is placed on the integration of Information and Communication Technologies (ICT), such as multimedia presentations and video lessons, to improve scientific literacy. Moreover, Bulgaria, promotes the project namely "Chemistry is all around the Network" to enhance European educational standards in its country (Koleva, 2013). Similarly, in East Asia, classroom settings use representational scaffolding (e.g., guided drawings, dual-coding diagrams, and stepwise narration) that increases clarity and on-task behavior (Xu, 2020). At the same time, in Azerbaijan, according to research, the implementation of inquiry-based learning (IBL) and project-based learning (PBL) boosts student participation; moreover, students understand clearly the explanations when tasks use real-life contexts and connections across subjects (Shahverdiyeva & Guliyeva, 2025). Findings indicate that, student engagement in chemistry lessons depends on how teachers during their explanation of chemistry concepts connects representational levels and integrate real-life examples, rather than only using group work or laboratory experiments. Therefore, going from the findings, this study will focus on how students describe their experiences in chemistry leaerning, particularly how representational explanations and real-life connections of chemistry concepts shape their engagement and understanding of this subject.

2.4.2 Homework/tutoring and exam preparation

Students mostly practicing formulas to prepare for exams when studying at home, which primarily relies on short-term performance on exams, however, it weakens their understanding of how macroscopic, submicroscopic, and symbolic levels are connected (Hsu et al., 2024; Chiu, 2022). Some countries implement methods to raise the effectiveness of students in studying. For example, in Ukraine, the established pilot program for grade 8 students intended to use Wordwall, showing that gamified practice in lessons increases the willingness of students to study, moreover, the research revealed that gamified and interactive tasks effectively motivate students, increase their interest in the subject, and boost engagement (Midak et al., 2025). The conducted research in Turkiye revealed that students who attended science tutoring sessions scored statistically significantly higher on the PNM diagnostic test than those who did not. This situation is visible in both standard multiple-choice questions and more complex "two-tier" questions that require students to provide a reason for their answer. The research was done using cross-sectional survey methodology where 382 middle school students (Grades 6–8) were involved to determine if attendance at tutoring centers impacted student performance (Özalp & Kahveci, 2015). Moreover, in Azerbaijan, the situation with emphasizing working with formulas, writing, and remembering also exists. State Examination Center (SEC) admission results on chemistry subject showed that a substantial weight relies on symbolic manipulation and representational translation that mostly encourage algorithmic rehearsal in homework and during tutoring periods, unless teachers deliberately connect procedures back to macro-submicro meaning (State Examination Center, 2025; Ministry of Science and Education & Institute of Education, 2023). Another study by Shahverdiyeva and Guliyeva (2025) indicates that when homework in science includes short reflective questions that are directly added into the task instructions (e.g., ‘Sketch a particle-level representation that explains these steps.”) or explicit examples that connect calculations to models, students demonstrate better comprehension and persistence. Similarly, the research on virtual-lab usage depicts that assigning short at-home simulation tasks with follow-up reflection questions assists students in managing representational links in independent study (Naghiyev, 2025).

While previously depicted studies indicate that structured homework tasks and short virtual-lab reflections can strengthen chemistry knowledge, mostly they focus on teacher-guided activities in controlled settings. Still, little is known about students’ perspectives on experiencing these tasks. Therefore, this study explores how students describe their experiences in chemistry in diverse settings.

2.4.3 Online/digital study

Students have an interest in simulations and virtual labs in chemistry lessons when they have clear goals and brief explanations that connect what has been seen in particle models with symbols. Research from Ukraine followed by an evaluation based on student feedback of 11th graders shows that Augmented Reality (AR) virtual chemistry laboratory helps students learn effectively, where the traditional classroom experience is converted into an interactive, independent research environment. Physical movement of markers that represent reagents play a substantial role in students' actively participation in virtual laboratories, in terms of interaction (Nechypurenko et al., 2023). However, there is no research in Ukraine about secondary school students. Across different educational systems, research demonstrates that the impact of digital chemistry tools depends mostly on the presence of instructional scaffolding while using during the lessons. For example, qualitative research that was done in Australia with 19 undergraduate students revealed that digital pens that students use in chemistry lessons allow students to engage in visual and real-time annotations, which is considered vital for understanding abstract chemistry concepts like molecular structures and reaction mechanisms. One of the primary themes identified in the research is "fostering focused learning", where the authors state that the technology enabled students to stay highly focused and task-oriented, noting that throughout four lesson observations, there were no records of off-task behaviors (Lee et al., 2021), and there is no research about usage of digital tools or conducting online lesson in chemistry at secondary-schools. The Azerbaijani program in chemistry learning (e.g., using inquiry, practicals, modeling, simulations, and real-life links) aligns with the global picture mentioned above (Ministry of Science and Education & Institute of Education, 2023). National research about online learning of the chemistry subject reports a positive framework in students' understanding, engagement, and motivation when virtual labs are effectively integrated into chemistry lessons (Pashayeva & Naghiyev, 2024; Naghiyev, 2025). However, in Azerbaijan, there is no in-depth research about the access of students to practical chemistry. This situation depicts a clear picture of the focus of this subject on centralized examinations that clearly prevent intended curriculum practices in chemistry subject from being effectively and reasonably integrated across schools.

2.4 Student Voices in Chemistry Learning

Research on students' voices in education provides a powerful framework for understanding how instructional practices are actually experienced by learners beyond what the curriculum provides. Rather than using students' feedback as an optional source of information, it should be used as diagnostic evidence that reveals whether instructional approaches support the creation of meaning in lessons or create cognitive barriers (Cook-Sather, 2019). In chemistry education, students' voices are crucial to consider, as the subject itself requires learners to navigate through multiple representations (Johnstone's triangle), handle abstract ideas, and preserve motivation while facing cognitive load (Talanquer, 2022). Examining students' voices in education allows researchers to witness how engagement and understanding of chemistry are enabled or disrupted across classroom lessons, homework/tutoring, and online/digital learning.

2.4.1 Students' Voices in Chemistry Lessons Across the World

Among different educational systems in countries like Finland, Singapore, Turkey, the United States, and the UK, most students indicate frustration in chemistry learning. These challenges are not related to the emotional state of students but are related to the representational levels in chemistry learning, as described by Johnstone (1982). For example, in Sweden, according to students' reports, chemistry becomes confusing when teachers, while explaining topics, move quickly between macroscopic, submicroscopic, and symbolic representations without explanations and bridging the relation between representational levels, leading students to a surface understanding of chemistry concepts without connecting to the real world (Aksela & Boström, 2012). Similarly, in Singapore, classroom-based research demonstrates that students struggle with stoichiometry (quantitative relationship between reactants in a reaction), not because of weak mathematical skills, but because of a lack of scaffolding by teachers on navigating students to connect symbolic equations to particle-level ideas (Chandrasegaran et al., 2007). Such ideas are seen in the United States also; students report that formulas seem overwhelming when macro-submicro-symbolic understanding is weak. Interviews with students revealed that when students perceive chemistry as a less difficult subject, when teachers support learning through particle drawings and step-by-step explanation of concepts that means developing clear instructions in macro-submicro-symbolic levels in learning chemistry (Becker et al., 2015). Moreover, students' ideas on chemistry in Turkey reveal that although they struggle to connect macro-micro-symbolic levels, and at the elementary level in chemistry subject abstract concepts are not understandable by pupils (Çalık & Ayas, 2005). In addition, the UK's research reveals that chemistry seems to students "difficult", "abstract" because of overload in macro-submicro-symbolic levels of understanding the concepts in chemistry, rather than a lack of ability or motivation (Taber, 2013).

Given previous global perspectives on students' voices across the world, it depicts that students' interests are central for improving chemistry learning and teaching; however, in Azerbaijan, there is a lack of qualitative, student-voice-centered research, precisely in secondary schools, on how students experience chemistry learning. Studies that exist in Azerbaijan mostly address curriculum intentions, teachers' practices in science, or exam performance of students; however, these studies do not capture students' perspectives on what supports or hinders their learning in chemistry. Therefore, there is a meaningful gap in understanding how Azerbaijani students “themselves” experience chemistry learning, and what factors shape their engagement in chemistry classes.

2.6 Summary

Reviewing the literature, the three themes were derived. First, the literature indicates that students’ meaningful understanding of chemistry depends on how the representational bridging is constructed; that is, how the instructional support that helps students to connect macroscopic phenomena, submicroscopic phenomena, particle models, and symbolic representations is created. Second, activities and tools (inquiry, hands-on or virtual labs, simulations) that are effectively implemented when teachers make scaffolding and debriefs. Third, about context that emphasizes infrastructure and assessment regimes that shape whether intended practices in chemistry subject are realized appropriately (McNeill et al., 2022). The outstanding gap in Azerbaijan is the absence of qualitative, secondary-school student-voice studies that examine the processes through which engagement is enabled or disrupted across classroom lessons, homework, tutoring, and online studying, contexts that existing literature identifies as central to students’ participation and understanding in chemistry. Addressing this gap in Azerbaijani literature, the present study seeks to understand how school students in Azerbaijan describe their experience in learning chemistry and which factors are essential to their engagement in chemistry classes.

CHAPTER 2: METHODOLOGY

This chapter will explain the methodological choice of this study on how secondary-school students in Azerbaijan experience learning chemistry and what factors influence their engagement in this subject.

The research questions of this study are grounded under the Interpretivist paradigm, which assumes that knowledge is co-constructed via interaction and context (Merriam & Tisdell, 2016). From this framework, understanding the participants' thoughts is central. Qualitative study was employed in this study, as it allows deep, rich, and descriptive exploration of human experiences (Creswell, 2012). A basic qualitative design (generic qualitative inquiry) was used in this research, as it focuses on describing and interpreting participants' points of view (Merriam & Tisdell, 2016).

3.1. Research Site

This research was conducted in one public and one private school which is located in Baku, Azerbaijan. The research sites were selected for their representativeness in implementing diverse chemistry curricula: the national curriculum in the public school and the international Cambridge program in the private school. The public school was chosen because the researcher got an access through formal administrative approval from the Baku City Education Department. Similarly, the private school was selected after receiving permission from the school principal. This school selection criteria ensured that the study was conducted in schools where official permission for research was got, rather than choosing schools only for convenience.

3.2. Participants

The participants of this study are students and teachers from public and private secondary schools in Baku. While the primary focus of this research is about the exploration of student voices in chemistry education, teachers were included in this research in order to provide triangulation and contextual depth to the students' reported experiences about chemistry learning. Considering that chemistry is first taught as an independent subject in Grade 7, and that this stage is when students develop the foundations of their chemistry knowledge, selecting students from 7th and 8th grades is appropriate for this study (Ministry of Science and Education & Institute of Education, 2023). The chosen participants from public and private schools gave a broad point of view in their experiences in chemistry, as chemistry is introduced in both private and public schools from Grade 7. Teachers were chosen based on the class that they told, secondary school chemistry teachers were chosen. In this research they gave deep insights on students' experiences in chemistry, and they enhanced and strengthened the data. Below in Table 1 the background information of participants are given:

Table 1. Participant Information

Participant Information	
Student 1	Gender: Male Grade: 8th School: Private Department: English Studying Program in Chemistry: Cambridge Curriculum
Student 2	Gender: Female Grade: 8th School: Private Department: English Studying Program in Chemistry: Cambridge Curriculum

Student 3	Gender: Female Grade: 8th School: Private Department: English Studying Program in Chemistry: Cambridge Curriculum
Student 4	Gender: Female Grade: 8th School: Private Department: English Studying Program in Chemistry: Cambridge Curriculum
Student 5	Gender: Male Grade: 7th School: Private Department: English Studying Program in Chemistry: Cambridge Curriculum
Student 6	Gender: Male Grade: 7th School: Private Department: English Studying Program in Chemistry: Cambridge Curriculum
Student 7	Gender: Male Grade: 7th School: Private Department: English Studying Program in Chemistry: Cambridge Curriculum
Student 8	Gender: Female Grade: 7th School: Private Department: English Studying Program in Chemistry: Cambridge Curriculum
Student 9	Gender: Male Grade: 7th School: Public Department: Russian Studying Program in Chemistry: National Curriculum
Student 10	Gender: Female Grade:7th School: Public Department: Russian Studying Program in Chemistry: National Curriculum
Student 11	Gender: Male Grade: 7th School: Public Department: Russian Studying Program in Chemistry: National Curriculum

Student 12	Gender: Female Grade: 7th School: Public Department: Russian Studying Program in Chemistry: National Curriculum
Student 13	Gender: Female Grade: 8th School: Public Department: Russian Studying Program in Chemistry: National Curriculum
Student 14	Gender: Female Grade: 8th School: Public Department: Russian Studying Program in Chemistry: National Curriculum
Student 15	Gender: Female Grade: 8th School: Public Department: Russian Studying Program in Chemistry: National Curriculum
Student 16	Gender: Female Grade: 8th School: Public Department: Russian Studying Program in Chemistry: National Curriculum
Teacher 1	Gender: Female Teaching Experience: 5 years School: Private Department: English Taught Program in Chemistry: Cambridge Curriculum
Teacher 2	Gender: Female Teaching Experience: 4 years School: Private Department: Turkish Taught Program in Chemistry: Turkish Curriculum
Teacher 3	Gender: Female Teaching Experience: 30 years School: Private Department: Russian Taught Program in Chemistry: National Curriculum
Teacher 4	Gender: Female Teaching Experience: 13 years School: Private Department: Azerbaijani Taught Program in Chemistry: National Curriculum

Teacher 5	Gender: Female Teaching Experience: 35 years School: Public Department: Azerbaijani Taught Program in Chemistry: National Curriculum
Teacher 6	Gender: Female Teaching Experience: 18 years School: Public Department: Russian Taught Program in Chemistry: National Curriculum *Additional Information*: Previously worked in private school, now in public

3.3 Sampling

For this study, students were chosen through a non-probability sampling approach, and within this category, the convenience sampling method was selected as the most practical and achievable option (Creswell, 2012). The chosen method of sampling is based on the willingness of the participants in the research, where rich data can be gathered (Creswell, 2012). The sample size in the research is based on the data-saturation principle, explaining that no new themes or insights appeared (Merriam & Tisdell, 2016). In this study, the sample size of students was set as 12-16 students (3 or 4 students from each grade (7th and 8th) and each school), and total number of student participants was 16, where saturation was reached. The study focuses on a relatively homogeneous group (lower-secondary students studying chemistry in Baku schools) and employs in-depth, semi-structured interviews (Merriam & Tisdell, 2016). Teachers were chosen through purposeful sampling. As this research is focused on secondary school students, chosen teachers are the teachers who are teaching to 7th and 8th graders. In qualitative research, participants are intentionally chosen based on their experience with the phenomenon rather than for statistical representativeness (Creswell, 2012; Merriam & Tisdell, 2016). In this research, teachers who teach 7th and high grades students were chosen to make an alignment with the classes where students study, in this case 7th and 8th grades. For this research 6 teachers were purposefully selected; 4 chemistry teachers from private school, and 2 chemistry teachers from public school.

After getting permission from the Baku City Education Department for the public school and for the private school from the school principal, the researcher went to the selected schools and chose the participants for the study. Giving the broad information about the study to the school principals, the consent forms were provided to select the participants, the assistant principal informed students in 7th and 8th grades and chemistry teachers about the study and invited volunteers to participate. From those students who expressed interest and returned signed consent forms, totally 16 students were chosen for interviews, and 6 chemistry teachers showed interest to participate in research. The principals of schools acted as gatekeepers, helping with sharing the information about the conducted study.

3.4 Data Collection

The data collection process was done via qualitative research data collection, precisely through conducting semi-structured interviews with participants.

Conducting semi-structured interviews. Data in this research was gathered through semi-structured interviews that allow researchers to flexibly ask questions to the opponents and explore answers more deeply (Merriam & Tisdell, 2016). Moreover, according to Galleta (2013), semi-structured interviews allow researchers to enrich the answers of participants by asking follow-up questions to obtain a deep understanding of the questions.

After the sampling phase, the researcher visited each selected school and met with the students who volunteered to participate in the study after being informed about the research by the school principals. Moreover, students' academic performance in chemistry was not used as a criterion for participation. During the meetings with the students, the researcher explained the purpose of the study, for what answers will be used, and answer participants' questions. To ensure the ethics of the study teachers were provided with consent form (see Appendix D), and students were provided with 2 type of consent forms: Parental Consent Form and Student Consent Form (see Appendix C), one for parents to sign and return, and the second for students to keep. According to the law of Azerbaijan, people under the age of 18 are considered children (Law on the Rights of the Child, 1998, Art. 1), and have limited rights to participate in legal agreements without consent form from their parents/guardians (Civil Code of the Republic of Azerbaijan, 1999/2023, Art. 30), and consent form for teachers.

Interviews were conducted face-to-face with students after lessons, and face-to-face interviews were conducted with teachers in flexible time with them after lessons at school. The duration of interviews is distinctive in teachers and students; while interview with teachers lasted approximately 30-40 min, interview with students lasted approximately 15-20 min. Each interview was conducted in a language that is suitable for participants; 8 students from private school gave an interview in English, 8 students from public school gave an interview in Russian language, 2 chemistry teachers gave an interview in Russian, 4 chemistry teachers in Azerbaijani language. With the permission of the students, the interviews were audio-recorded. For reporting the data, specific segments of the transcripts that directly addressed the research questions and illustrated the emergent themes were translated to English language, with special attention to keeping meaning and cultural nuances through careful researcher-led translation and cross-checking of transcripts.

Two interview protocols were created. One for students (see Appendix A) and another for teachers (see Appendix B) consisting of open-ended questions about students' experiences in learning chemistry determining how students understand and connect macroscopic, submicroscopic, and symbolic representations in lessons, their engagement in inquiry-based and practical activities, their perceptions of learning tasks or tools that they find supportive or challenging for comprehending chemistry concepts, and their experiences studying chemistry at home or using digital tools. Teachers in the interview were asked about students' experiences with chemistry lessons, about students' engagement to lessons, precisely which factors play a role in students' engagement in chemistry lessons and their understanding in chemistry. The semi-structured format of the interviews allowed both students and teachers to elaborate on their experience and provide the opportunity for follow-up questions if clarification is needed. The gathered data allowed the researcher to make constructive comparative analysis between public and private school education in chemistry, and see the deep distinction between Cambridge and National Curriculum in Chemistry.

3.5. Data Analysis

Qualitative analysis of data was done simultaneously with data collection. Each completed interview was transcribed, and useful moments for the analysis were translated into English (if the interview has been done in another language), and automatically subjected to initial open (coding) to identify meaningful data units that could be used in further transcription of interviews. According to Saldaña (2013), a code is a short word or phrase that summarizes and captures the main idea from a specific part of the data. Defined codes were grouped into categories and refined into themes that linked to the research questions.

Firstly, transcripts of interviews were refined and imported into a project folder. After each interview, analytic memos were written in the researcher's notebook to capture the ideas from the gathered data. These created memos guided the reflection and minor changes to later interviews (Merriam & Tisdell, 2016).

Secondly, in the initial coding phase, using open coding, descriptive and process codes were assigned to segments that reflect students' experiences across classroom, homework, tutoring, and online study.

In the next steps, codes were compared within and across cases to collapse the redundancies and surface conceptual categories. Constant comparisons of data guide how categories are defined and linked (Merriam & Tisdell, 2016).

Defined categories were developed into themes that directly answer the research questions. Themes that were created from students' transcripts were triangulated with teachers' transcripts to check the similarities and differences between what students report and what teachers report.

A working codebook (code names, definitions, inclusion/exclusion criteria, examples) was updated across work cycles. To ensure credibility, codes are discussed with the supervisor. The comments of the supervisor helped in making some refinements in codes and made themes clearer.

After completing 22 interviews (16 interviews with students, 6 interviews with chemistry teacher) no new themes or categories emerged. Therefore, data collection was ended with 16 student participants and 6 chemistry teachers, marking the point of saturation, the situation when additional data no longer provides new insights (Merriam & Tisdell, 2016; Saldaña, 2013).

3.6. Trustworthiness

Following the criteria that Lincoln and Guba (1985) mentioned, the trustworthiness of this qualitative study was addressed via credibility, dependability, confirmability, and transferability. These criteria guide the procedures used to collect, analyze, and present the data.

Credibility

Credibility was used for tracking the accuracy and probability of the findings for the participants and the studied context (Lincoln & Guba, 1985). In this study, credibility is established through triangulation and peer review.

Triangulation. Triangulation is a strategy that used in qualitative research to increase the credibility and trustworthiness of findings through using using multiple data sources, methods, or perspectives to examine the same phenomenon (Creswell & Creswell, 2018). In this study, triangulation was achieved by cross-referencing multiple data sources, including semi-structured interviews with students and teachers alongside the researcher's analytic memos. While initial findings were compared across these sources to check for consistency, the final interpretation of results in relation to the literature review was conducted during the analysis and discussion phases to ensure theoretical credibility.

Peer review. The peer review process involves presenting emerging findings to colleagues for feedback (Morse, 2018). Credibility of the findings was further supported through ongoing peer discussions and during the meetings with supervisor, where preliminary codes and categories were discussed. Moreover, the methodology and emerging findings were reviewed and discussed by thesis committee members during the thesis, development, allowing for refinements in code definitions and clarity of themes before the final submission.

Dependability

Dependability in this research refers to the consistency and traceability of the research process and results (Guest et al., 2012). In this study, it was strengthened through triangulation (involving teachers to the research) and the creation of an audit trail.

Audit trail

An audit trail documented the study's procedures and decision-making processes (Merriam & Tisdell, 2016). During the research a research journal was maintained from the beginning of data collection to the completion of theme development. The journal included dated memos, interview protocols, consent forms, sampling, scheduling notes, codebook revisions, and records of analytical decisions. These documents provided transparency and allowed readers to witness how interpretations of the research were formed.

Confirmability

Confirmability in this research was addressed by ensuring that interpretations are grounded in the data rather than in researcher assumptions (Lincoln & Guba, 1985). Reflexive notes were kept throughout the study to support awareness of the researcher's role, and all interpretations were accompanied by anonymized excerpts from interviews and observations to demonstrate clear links between evidence and conclusions.

Transferability

Transferability (external validity) in this research to the extent to which findings may apply to other contexts (Lincoln & Guba, 1985). It was supported through rich, thick descriptions.

Rich and thick description.

Rich description in this study means the detailed information about the research setting, participants, and procedures with supporting evidence (Merriam & Tisdell, 2016). In the findings chapter of the thesis, information about the schools was provided, and quotations from interviews with students and teachers were included. These details enable readers to determine the relevance of the findings to other educational settings.

Ethical Considerations

Ethical considerations in this study guided through all stages of the interviews (British Educational Research Association [BERA], 2024). The procedures demonstrated below followed before and during data collection.

Informed Consent and Assent

Before participation, students, their families, and chemistry teachers received information about the study's purpose, procedures, confidentiality, and the voluntary nature of participation. Because the students are minors, both parental/guardian consent and student assent was required before scheduling interviews. Information sheets and consent/assent forms, where consent form for parents is a legal permission granted by an adult (parent or guardian) allowing their child to participate in the study, and assent form, where refers to the minor's own voluntary agreement to participate in the research. While consent is a legal requirement from an adult, assent ensures the child's autonomy is respected and that they have personally agreed to the process in an age-appropriate manner, noted that participation is voluntary and may be withdrawn at any time without consequences (Iphofen, 2009).

Confidentiality and Anonymity

Confidentiality in this study was ensured by removing identifying information from transcripts. Nicknames used for students, teachers, and schools in all documents are anonymous. Any identifying details mentioned during interviews were anonymized or generalized.

Data Security

Audio files, transcripts, and field notes were stored on a password-protected device that is accessible only to the researcher. Audio recordings from interviews were deleted when transcription accuracy was checked. Consent documents were stored separately from research data to prevent linkage.

Minimizing Risk and Respect for Participants

To respect the participants' time and school schedule, interviews were conducted after school hours as previously described. Questions in the interviews focused on learning experiences in chemistry and did not include sensitive personal topics. At the beginning of each interview, participants were reminded that they may skip any question or stop their participation in the study at any time.

3.7. Delimitation of the Study

This study has concluded that this research was done in lower-secondary chemistry education that focuses on students and chemistry teachers in 7th and 8th grades in public and private schools in Baku. Other grade levels, like high school students, were not included because the aim is to examine how students at the introductory stage of formal chemistry instruction experience the subject itself. The focus of this study is limited to the chemistry subject and did not include other school subjects. The research design employed qualitative methods like semi-structured interviews with students and chemistry teachers to explore students' learning experiences in-depth. The given delimitations of this study helped define the scope of the study and maintain alignment with its research purpose.

3.8. Limitations

This research has got several limitations. First, the study was conducted in two schools (one private, one public) in Baku that were selected based on accessibility and administrative approval. Therefore, the findings of this research are not intended to demonstrate the situation in all schools across Azerbaijan, particularly those in rural places.

Second, the interview time with students was one of the limitations. Despite their big interest and voluntary participation in the study, some students were not talkative a lot, giving one or two sentences. This situation limited the opportunity to receive in-depth information from some students. Moreover, as participation in this research is voluntary, the selected students for the interview were students who are more engaged in chemistry and science, which may limit the diversity of captured perspectives from interviews.

Despite these limitations, this study aims to contribute to understanding how lower-secondary students in Baku experience learning chemistry and what factors shape their engagement with the subject.

CHAPTER 4: FINDINGS

In this study, two research questions were explored: How do students at secondary schools in Azerbaijan describe their experiences of learning chemistry? What factors contribute to student engagement in chemistry classes? From the gathered data several themes emerged in both research questions. In this chapter, the findings for the data, themes according to the research questions are provided.

Research Question I: How do students at secondary schools in Azerbaijan describe their experiences of learning chemistry?

To find out the answer to this research question, students from private and public schools were asked about their experience in chemistry subject, including their daily chemistry lessons, in which way they understand the subject better, and their experience with chemistry outside the school. From the data, relevant to the first research question, several themes and subthemes were explored:

Learning Chemistry as a Process of Conceptual Struggle

For many students in private and public schools in Baku, the initial encounter with chemistry is defined by a struggle of the abstract nature of the subject. This challenge comes because of the disconnection between macroscopic observations and the symbolic language of the chemistry subject. This difficulty reflects a struggle within Johnstone's Triangle concept, where students find overwhelming to navigate between the visible world and the submicroscopic level represented by formulas and equations. Students see chemistry difficult because it uses symbols and concepts that are challenging to link to reality.

The challenge in understanding the abstract symbols in chemistry concepts is noted by Student 4 from private school, who reflected that challenges happened in the introductory level of the subject. Student 4 says: *"So, when we first started learning chemistry, it was in fifth grade as I told you. Like, I didn't understand the purpose of chemistry. I was like okay it's an element, it's something, maybe we couldn't even see it, we couldn't even touch it, why do I need this."* This data illustrates that the conceptual struggle begins when students cannot link the submicroscopic (what is interpreted from observation) level of elements and atoms to their own macroscopic world. Without clear "bridge talk" between these levels, the student perceives chemistry as an invisible academic requirement rather than a tool for understanding the physical world.

The heavy use of symbols and numbers makes chemistry harder to understand and can reduce students' early interest. For example, student 11 from public school noted the overwhelming volume of formulas in chemistry: *"В третьем разделе там было очень большое количество формул, которые очень сложно было выучить"* [In the third section, there was a very large number of formulas, which were very difficult to learn]. This situation shows that students often memorize formulas instead of truly understanding them, because of the challenge to logically connect formulas.

Mathematical skills and "Mathematical" Topics in Chemistry as a Form of "Challenge" in Understanding Chemistry Concepts

According to the findings, students identified mathematical knowledge as a prerequisite in some topics in chemistry and in developing conceptual understanding. Participants emphasized that many core chemistry topics, such as balancing chemical equations, require not only basic arithmetic but also the ability to apply mathematical reasoning in abstract contexts. From this point of view, mathematics is not seen as a separate subject but as an essential one that supports students in understanding some topics in chemistry. For example, student 13 from public school expressed a strict belief that for understanding chemistry math knowledge is important: "*Я думаю, если не знаешь математику, то объективно не знаешь химии"* [I think that if you don't know mathematics, then objectively you don't know chemistry]. Moreover, this idea was reinforced by Student 15 from public school, who directly linked their personal difficulties in the subject to their perceived weakness in mathematical skills, stating, *"Мне кажется, это связано с математикой* [It seems to me that this is related to mathematics]".

This kind perceptions create a psychological divide where students who view themselves as "humanitarian-oriented" may feel disappointed while learning chemistry, as they believe that their cognitive profile is incompatible with the subject's requirements.

The struggle with connecting math with chemistry is mostly emphasized in topics that transform chemical principles into algorithmic challenges, such as the balancing of chemical equations. Student 8 from private school identified this as a major barrier, noting that it was a topic "that I failed in exams" because of the requirement to accurately connect math and chemistry. Teacher 1 from private school confirmed this experience, explaining that students "mostly find topics requiring mathematical and logical thinking more difficult to understand"["*riyazi-mentiq tələb eləyən mövzuları daha çətin qavrayırlar"],* particularly when lessons move toward the rate of chemical reactions or solution-based calculations. These findings suggest that the moment when chemistry moves from theory into "calculation-based parts," many students experience an immediate increase in conceptual understanding.

This "technical vs. humanitarian" divide is not merely a student perception but also is reflected by chemistry teachers, categorizing students' potential in studying. Teacher 2 from private school:

> Məsələn, o baxır, uşağın hansı riyaziyyatda, daha doğrusu uşaq texniki təmayulli, yoxsa hümanitar təmayulli şagirdir buna baxır. Niyə? Çünki riyaziyyat hesaplamaları sevən şagir, artıq molun tapılması, avogadro sabiti, kimyəvi təhlilərin hesaplanılmasını sevir. [For example, it depends on the student, more precisely, whether the student is inclined toward technical subjects or humanities. Why? Because students who enjoy mathematics also tend to like calculations, such as finding the mole, using Avogadro's constant, and performing chemical calculations.]

Similarly teacher 6 from public school identified this divide as a primary factor in student success, noting that students with a strong technical direction have got a superior "perception" of chemistry because they can handle the calculations involved in the mole concept or Avogadro's constant topics. Teacher 6 says:

> То есть бывают знания ученики, склонные к техническим предметам или же гуманитарным предметам. Обычно ученик, который с техническим уклоном, он и хорошо знает математику, и физику, и химию у него уже хорошее восприятие [That is, students tend to have either a technical or a humanities orientation. Typically, a student with a technical inclination has a good understanding of mathematics and physics, and therefore also perceives chemistry more effectively.]

Similarly, teacher 2 elaborated the statement: *"uşaqlar ki, sırf hansı ki əzbərləməyi sevirlər, yadda qalma, metn oxumagi sevirlər, onlar onu sevmirlər, çünki riyaziyyət hesaplamaları artıq onlara çətin gəlir, riyaziyyət hissəsi çətin gəlir* [students, those who prefer memorization, retaining information, and reading texts, do not enjoy this, because the mathematical calculations feel difficult for them], emphasizing that students who "prefer memorization, retaining information, and reading texts, do not enjoy this (mathematical calculations)" because the mathematical components feel inaccessible. According to tecahers' and students' reports, success in understanding chemistry is often considered something that depends on technical ability, which lead to the thinking among stduents that chemistry is only for those who are good at math, instead of seeing it as a subject that anyone can understand through different ways of learning.

The Construction of Understanding Chemistry: The "Parallel Learning System"

The concept "parallel learning system" emerged from the thematic analysis of this research as a critical "compensatory" structure defining the secondary school students' experience. This system represents the marked boundary that students perceive between formal classroom lessons in chemistry and out-of-school environments in studying chemistry, including homework, private tutoring in the form of family member support, and digital tools. While school settings provide the initial encounter to chemical concepts, the findings suggest that the "parallel" learning system is what helps the actual construction of conceptual understanding happen. As a result, students use this system to deal with limits of the school curriculum, helping them better understand abstract ideas in their own time outside class.

Digital Tools. Digital tools play an important role in this system by helping students understand chemistry better, especially by visualizing the particle level that may not be often clearly explained during the regular lessons. For example, student 3 from, attending a private school, demonstrated a sophisticated approach to these tool*s,* emphasizing a desire for conceptual clarity over simple answer-seeking: *"I ask AI to explain it but not tell the answer... I ask it to explain and then try to find an answer on my own."* This proactive behavior of a student indicates a high degree of metacognitive awareness, as the student recognizes their own cognitive gaps and seeks digital support to better construct the understanding of chemistry concepts. Similarly, student 2 from private school also indicated that for answering the questions that are unclear, the student uses AI: "*If I have a question I will mostly search it in AI"*. This situation indicates that AI tools are a part of the "parallel learning" concept for conceptual understanding in chemistry.

Role of Family Members. Another part of the "parallel learning system" is family support, which gives students personal help and makes the students feel the subject less abstract. In the absence of immediate school-based support, family members frequently engage in "bridge talk," translating complex scientific representations into accessible, everyday language. The help from family members is mentioned by Student 14 from a public school, who described different levels of support from outside the classroom: *"У меня бабушка химик…….Если что-то непонятно…..спрашиваю у старшей сестры. А если уже и это не помогает, то мы звоним бабушке* [My grandmother is a chemist… If something is unclear, I ask my older sister. And if that still doesn't help, we call my grandmother]. Such access to intergenerational expertise allows students to navigate the challenges with symbolic language of the chemistry curriculum, effectively using the home environment as a space for informal tutoring and representational translation. Similarly, student 3 from a private school also indicated that the family members support when something is unclear in chemistry: *"I took advice from my parents and I asked them to explain chemistry deeply"*. This situation demonstrates that family members play a crucial role as an external support besides the school, helping to strengthen conceptual understanding in chemistry.

Homework. When this kind of "bridge talk" (real discussions during the lessons for connecting macroscopic, submicroscopic, and symbolic levels in understanding chemistry concepts) is not available at home, students rely more on doing homework on their own, which helps them move from simple memorization to real understanding.Instead of seeing homework as a chore, students see it as an important extension of the lesson, which helps them understand complex chemical laws that cannot be fully learned in one class period.. For example, student 15, a public school student, summarized this idea by stating*: "Если бы не было домашнего здания, то я бы не понимала* [If there were no homework, I wouldn't understand]*,* or student 8 from private school indicates that homework is an important part for understanding chemistry much more better: *" homework is really important you to understand some topic better*". These reflections show how important independent practice is, as it gives students time to think and helps them move from simple repetition to a deeper understanding of the subject.

In summary, digital tools, family support, and homework together form a "Parallel Learning System" that helps students deal with the difficulties of understanding chemistry. These supports help students connect what they see (experiments), what happens at the particle level, and chemical formulas better than they usually do in class.

Summary

The research question 1 in this research explores how secondary school students in Azerbaijan describe their experiences of learning chemistry. According to reports, chemistry subject is widely perceived as a challenging one due to its abstract nature and the difficulty of connecting macroscopic observations with symbolic and submicroscopic representations. Students often rely on memorization, rather than understanding deeply the concepts, especially, understanding is lack, when "bridge talk" between representational levels is note done accordingly. Additionally, mathematical skills emerge as a major barrier in understanding chemistry concepts. Both students and teachers view success in chemistry in knowing math, which creates a perceived divide between "technical" and "humanitarian" learners. To cope with these challenges, students develop a "parallel learning system," where meaningful understanding is constructed outside the classroom through digital tools (e.g., AI for explanations), family support, and homework. Overall, the findings suggest that students' experiences of learning chemistry are shaped not only by classroom instruction but also by external support that help them to make complex chemistry concepts easy to understand.

Research Question II: What factors contribute to student engagement in chemistry classes?

To find the answer to this question both private and public school teachers and students were asked about the factors that play and promote students' engagement in chemistry lessons, related to different types of engagement (behavioral, affective, cognitive engagement). Students were asked about the activities in which they are involved and other factors that shape their engagement to this subject. Similarly, teachers' were asked to provide the framework about students' engagement to the lesson; factors and barriers that shape or disengage students from the lessons. According to the data, several themes and subthemes were extracted for research question II:

Behavioral Engagement Domain.

Behavioral engagement encompasses student's visible and active participation in the learning process, serving as a primary indicator of their practical investment in the subject learning. This domain may contain a wide range of observable actions, including attention during lessons, the consistent completion of assigned tasks, and help-seeking behaviors. In the context of secondary chemistry education in Baku, behavioral engagement factors are active note-taking, the frequent posing of questions, and participation in laboratory works. Below are given factors that identified through analysis of data and contribute to behavioral engagement of students:

Experimental and Hands-on Learning. Laboratory work and visual demonstrations considered are the most effective factors in order to engage students in chemistry lessons, as these dimensions are able to make abstract concepts in chemistry more real and interesting. In private schools, students often enjoy the "scientist" experience, participating actively in experiments such as making salts, example of student 8 from private school: *"We are making experiments. It's real that you are a scientist and you are making experiments to maybe help the world''.* This sense of purpose stems from the student's ability to see the macroscopic results of their work, such as the formation of a solid salt from liquid reagents, which transforms the 'invisible' symbols of a textbook into a tangible, real-world contribution. Moreover, private school students use their senses (like seeing or observing experiments) to better understand complex chemical concepts. For example, student 2 from private school highlighted that the value of direct observation is the ability to see in real time what happenes with chemical processes: "*Lab experiments, we can see it in reality how... we can see with the eye. We can know how the gas is produced, how the rate of the reaction is happening, and the color of the reaction in real life".* This observation demonstrates the successful navigation of Johnstone's Triangle, where students bridge the macroscopic level of visual phenomena with submicroscopic models. This kind of "bridge talk" helps students clearly navigate through representational levels, linking experiments to the theory. Moreover, student 3 emphasized the value of practical involvement in chemistry lessons: *"I'm 100% sure lab activity is the best way to understand chemistry. We have been to the lab recently, and we made salt in the lab here. That made me understand that topic even deeper, and, like, I understood it so much better after the lab activity."* This statement confirms the idea that when students move from the memorization of theory to physical interaction with chemical processes, and consequently, their comprehension in complex chemistry complex increases significantly. The laboratory lessons are able to turn difficult, abstract ideas into something students can explore and actually want to learn.

In contrast, in public schools students mostly just watch while the teacher does the work, so they play a passive role instead of actively doing science. Example of student 16 from public school: *"...так эксперименты мы сами не проводим. Учитель может проводить, и мы можем подходить, или если там какой-то продукт образовался, просто его берут все* [… We don't actually conduct experiments ourselves. The teacher may carry them out, and we can come closer to observe, or if some product is formed, everyone just takes a look at it]". Similarly, student 15 described a typical encounter in the laboratory where "the teacher demonstrated it (color changes in product), but we were not allowed to do it ourselves". This strict teaching style puts the teacher in full control and creates a strong distance between students and the actual process of doing science. By not allowing active participation of students in laboratory works, the school environment limits inquiry-based learning and prevents students from developing their own sense of thinking and acting like scientists.

The lack of active participation of students leads to a state of frustrated engagement, where students recognize the value of visual data but are denied the opportunity to generate it themselves. Student 13 acknowledged that seeing visual changes, such as an acid changing the color of a paper, "really helped me understand the topic," yet noted that the experience was characterized by "seeing something" rather than "doing". This situation shows that even though students can see experiments (macroscopic level in Johnstone's Triangle theory), their understanding stays at a surface level because they don't get hands-on practice. Without hands-on experience, students struggle to move from formulas to real understanding, leaving them interested in laboratory work but not fully engaged in it.

Furthermore, not allowing students to use lab equipment creates a barrier that stops them from developing important practical skills. For example, student 12 from public school shared a situation where "only once they were shown some equipment in chemistry lab but students were not allowed to touch it, because the teacher did not want to allow that".These limits mitigate students from developing skills and support a teaching approach that protects equipment more than it builds hands-on abilities. This limitation shows a clear gap between students' interest in hands-on learning and a school environment that only lets them watch from a distance.

Teachers also utilize the laboratory lessons as a sociological tool; for example, Teacher 2 from private school noted that the lab is often used as a "reward" for good classroom performance, indicating that practical work is seen as something special, which motivates students to behave well and stay focused:

> Aktiv olmayan uşaqlara da artıq biz etkinliklərlə diqqətini çəkməyə çalışırıq, laboratoriya getmək, getməmək kimi söhbətlərimiz olur ki, əgər dərsə yaxşı cavab versəniz, laboratoriya işində sizi sərbəstlik veriləcəkdir [For less active students, we try to capture their attention through activities. We have discussions about going to the laboratory or not, for example, if you respond well in class, you will be given more independence during laboratory work].

Moreover, one of the methods to involve and engage students in chemistry subject, teacher 5 promotes some small experiments such as paper chromatography at home and then in class talk about results and making the experiment again in class some students could not do it at home: *"Məsələn, biz 7-ci sinifdə kağız xromotografiyasını keçirdik. Məsələn, mən uşaqlara evdə də tapşirdim ki, həmin kəğız xromotografiyasını özləridə təcrübələrini evdə aparsınlar"* [For example, in Grade 7 we studied paper chromatography. I also assigned students to carry out this experiment at home]. This evidence suggests that practical work is not only used for learning, but also as a tool to manage student behavior and increase engagement. Moreover, this evidence also shows that teachers rely on experiments, both in class and at home, to make chemistry more interactive and meaningful, especially for less active students.

Asking questions. This factor of behavioral engagement emerged as a critical behavioral indicator of student engagement, when conceptual clarity was missing. According to the student engagement framework (Bond et al.,202), this behavior demonstrates a student's active participation and willingness to take responsibility for their own learning process. Going from the analysis in this study, students who demonstrated high behavioral engagement did not remain passive when faced with the "conceptual struggle" of abstract chemistry topics, instead they immediately ask teachers to explain complex chemistry concepts for better understanding. One of the examples is the Student 1, who emphasized to the effectiveness of this strategy, stating: *“And if I still don't understand, I'm gonna ask the teacher. And after that, I will understand”*. This data suggests that for many students the teacher play a crucial role, serving as "real-time" scaffold, where the act of questioning allows for the repeated explanation that isnecessary to decode complex symbolic language. This behavior was not limited to the classroom; some students, such as Student 2, even find out teachers privately to further discuss difficult concepts, showing that asking questions is a primary tool for moving from confusion to mastery. Student 2: “*And I had a really hard time learning. Then I started to show some interest, asking the teacher, talking to the teacher privately about can I learn this, this, and she explained it very well, and like, eventually, I learned it……and I understand chemistry.*

Note taking. This dimension of behavioral domain was identified by both students and teachers as an essential active learning behavior that critically play an integral role in the translation of abstract chemical concepts into written records. Within the behavioral engagement domain, the physical act of writing is seen not merely as a passive recording of information but as a necessary cognitive tool for mastering the subject's symbolic language. Teacher 4 emphasized this situation strongly, stating: *"In general, a student learning chemistry should always have a pen and a notebook with them. They must learn by writing".* This perspective suggests that the complexity of chemistry requires a motor-sensory engagement to the subject to reinforce memory and logic. Student 3 confirmed this statement: *"Taking notes is really essential for me to understand, especially in chemistry"*. The data further revealed that note-taking serves different functions depending on the instructional context. For instance, teacher 1 requires students to use A4 sheets during laboratory work specifically to record observations, in order to a move from visual observation to conceptual documentation. Similarly, in research-based tasks, students use notes to create schemes and diagrams that help them organize their thoughts before presenting to the class. While this note-taking practice was prevalent in private schools, public school students also used note-taking strategy for organizational purposes. For exsmple, student 14 creates tables and charts to help "all subjects" become clearer. Student 14:"*Я иногда делаю таблицы, и вообще по всем предметам мне таблицы помогают* [I sometimes create tables, and in general, tables help me across all subjects]".

Cognitive Engagement Domain.

Cognitive engagement of students is a domain that encompasses several factors related to students' learning and understanding the chemistry concepts. The factors of cognitive engagement can be mental effort, reasoning, and self-regulated learning strategies that students integrate in order to master complex ideas and persist through challenging tasks. Within the context of secondary chemistry education, cognitive engagement is specifically characterized by a student's ability to navigate Johnstone's Triangle concept, effectively coordinating between macroscopic observations, submicroscopic particle models, and abstract symbolic representations. This domain represents a critical shift from surface-level rote memorization toward meaningful conceptual processing, where students attempt to construct a logical framework for understanding the "invisible" world of atoms and molecules. Acoording to the findings of this study, cognitive involvement of students to the chemistry subject is deeply influenced by the quality of instructional scaffolding, particularly the teacher's use of everyday metaphors, and "household language" to reduce abstraction. Consequently, cognitive engagement is achieved when students are supported to make real-world connections of complex chrmistry concepts, allowing them to interpret chemistry subject as the essential one in their everyday lives.

The cognitive factor of engagement in this research that is considered through analysis of data is "use of metaphors and real-life links of concepts". A key way to engage students is by using everyday metaphors to make abstract chemical ideas easier to understand. For example, teacher 4 from private school shared a method of using familiar social and physical analogies, comparing physical properties to a person's "outward appearance" and chemical properties to their **"**internal character traits," such as patriotism or diligence. To assist with memorization and acid strengths, this teacher employs a "horse and dog" analogy, explaining that "the 'horse' is bigger, so the substances associated with it have greater valency or strength". This use of simple connections is also seen in how students understand the concepts, in example of student 16 from public school who mentioned that chemical transitions are observable in daily routines: *"Допустим, на обычной повседневной жизни, допустим, когда ты жаришь яичницу, оно из одного состояния перетекает в другое и уже становится более понятно"*[For example, in everyday life like when you fry an egg, it changes from one state to another, and this makes it easier to understand. This "life integration" strategy acts as a catalyst for cognitive engagement, as noted by Student 2 from private school who concluded that "chemistry is basically life" because it encompasses everything in the world.

Affective Engagement Domain.

Affective engagement domain refers to the emotions of students that students feel during learning and engaging to the subjct. The factors of cognitive engagement can be interest, enjoyment, motivation, boredom, frustration, or anxiety toward the subject. This dimension of engagement is important because students' emotions strongly influence their willingness to participate in the lessons and involve to the learning of subject, especially when students face difficult concepts in the subject. Positive factors, such as supportive teachers, enjoyable activities, and peer collaboration, can increase students' motivation and confidence. In contrast, negative factors, including chemophobia and classroom distractions like noise, may reduce participation and interest. Overall, affective engagement creates the emotional atmosphere of the classroom and influences students' motivation to learn chemistry even before they begin solving formulas or equations. According to the analysis of data, the affective engagement factors were divided into two group: positive affective factors and negative affective factors. The dimensions of each category are given below:

Positive Affective Drivers.

Teacher Personality. Students often said that the way the teacher teaches and the attention they give to each student strongly affects their willingness to engage with difficult topics. For example, student 3 from private school expressed a strong emotional connection to their instructor's method, stating: *"I love my chemistry teacher. She explains everything so* *deeply... a good teacher is really important for us to understand everything"*. By simplifying complex information and creating a supportive environment, teachers like Teacher 3 from private school aim to help students to "develop an interest in the subject" through individualized approaches: *"".. кому какой индивидуальный подход, что надо делать, чтобы они полюбили вот этот предмет"* [You begin to recognize what kind of approach each student needs and what should be done to help them develop an interest in the subject]. These examples show that for 7th and 8th grade students, how difficult chemistry feels often depends on whether the teacher communicates with them, not just talks at them.

Gamification. This domain of positive affective drivers in affective engagement of students considered the crucial one that enhances student engagement to the subject by mitigating the boredom that often associated with the abstract nature of the chemistry subject. Within the affective engagement domain turning lessons into interactive experiences serves to build a positive emotional climate and stimulates intrinsic interest in the subject. Teacher 1 explicitly described this pedagogical choice, stating: *"So that it does not become boring, we turn the lessons into something like a game to some extent combining learning, play, and enjoyment"*. This approach in involving students emotionally to the lessons often includes role-playing activities and team-based competitions, which construct the classroom dynamic, shifting from a passive lecture during the lessons to an active, socially interactive environment while learning. Students reported high levels of enjoyment in these formats. For instance, student 7 described playing games to identify chemical symbols as "really funny and it's interesting" during the chemistry lessons. The data suggests that gamification is particularly effective while leaning symbolic language in the subject, which students mostly found overwhelming. Moreover, teacher 3 noted that digital game-based platforms had a significant impact on students' performance, observing that students who previously “could not distinguish metals from non-metals” improved their understanding when the task was presented in a game. This interpretation implies that the joy derived from gaming reduces the cognitive friction of memorization. In addition, student 3 emphasized that the emotional engagement in thechemistry lessons is powerful when the lessons involve “cooperating with others... like quiz games” and “challenges with each other like competitions” highlighting that the affective joy of gaming is deeply linked to peer collaboration and social belonging. Consequently, gamification acts as a scaffold that supports students’ emotional persistence, transforming what they perceive as "resistivity" while learning the chemistry concepts, shifting from the individually learning, understanding complex topics into a shared experience of play and discovery of chemistry concepts.

Peer Collaboration as Emotional Support. Collaborative learning and peer support while learning the chemistry concepts considered as a vital affective driver that provide students with a sense of comfort and belonging which is often absent during traditional, teacher-led instruction. Within the affective engagement domain, the emotional safety of the peer group allows students to navigate the through the "conceptual struggle" in chemistry without the fear of judgment that they do not undewrstand chemistry. A key finding was that students valued “student language,” explaining that simple peer-to-peer explanations of abstract concepts easier to understand than the teachers’ complex scientific language. Student 8 from the private school articulated this benefit clearly, stating: *“Friends explain topics in our language, so group work helps us understand chemistry better”.* The interpretation of this data means that peer support serves as an informal, emotional factor during "bridge talk", where students translate symbolic and submicroscopic concepts into a familiar language. Student 8 further explained that because friends are from the same generation, they “understand what you want to understand”, whereas teachers may not always grasp the specific nuances of a student's confusion. Such interaction among students is able to reduces the distance between students and learning, helping them feel less uncomfortable with difficult topics such as balancing equations or the reactivity series. By working in teams and engaging in "challenges with each other," students transform a potentially isolating academic struggle into a shared social experience. Consequently, this sense of peer collaboration fosters a positive emotional climate, making students feel more confident and motivated to persist in a subject that they initially perceived as abstract and challenging.

Negative Affective Drivers.

Classroom Noise. Engagement of students in lessons is frequently disrupted by "environmental dimensions" that hinder the meaning-making process. Students, particularly in the public school, identify classroom noise and disruptive behavior as primary reasons for their lack of focus, example from student 9 in public school described how environmental factors weaken the quality of teaching: *"Но когда химия была непонятной, это не было потому что учитель плохо объяснял, это было потому что весь класс шумел, и я сам тоже отвлекался и не смог видеть, слышать голос..."* [But when chemistry was unclear, it wasn't because the teacher explained poorly; it was because the whole class was noisy, and I was also distracted. I couldn't see or hear properly...]. Similarly, student 12 from public school confirmed this idea, stating that *"когда все кричат, перебивают, то есть, уже урок все неинтересно"* [when everyone is shouting and interrupting, the lesson stops being interesting]. This data demonstrates that how classroom noise and interruptions negatively influence students' emotional engagement and interest in chemistry learning.

Chemophobia. Psychological barriers like "chemophobia" (fear of chemistry) also strongly reduce student engagement. Teachers say this fear is often learned from parents or society, where chemistry is seen as a very difficult subject, example from teacher 4 from private school who noted that this "chemistry phobia" exists before the student even enters the classroom, creating a lack of confidence that prevents students from participating in discussions or experiments:

> *"yəni 7di və 8lərdə burada o şagirdlərə dərs vermək təcrübəsi necə deyim mən sizə ki, bax, təsəvvür edin ki, o şagirdlər yeni başlayır və kimya adı gələndə bir kimya fobiya var, bir kimya qorxusu var. Sanki o, valideynlərdən mi gəlir şagirdlərə, yoxsa eşidirlərmi cəmiyətdə?... Mənim həmişdə qorxum nə olub?Ən çox da bunu dövlət məktəblərində hiss eləmişəm.Və yaxud da özəl məktəblərdə bəzən hiss eləmişəm. Uşaqların kimyadan əvvəldə bir qorxusu olub və maaləsəf ki, bu kimya fobiya var* [In Grades 7 and 8, teaching those students is such that, how can I explain, imagine that they are just starting, and when they hear the word 'chemistry,' there is already a kind of chemistry phobia, a fear of chemistry. It seems as if this comes either from parents or from what they hear in society…This has always been one of my main concerns. I have noticed it especially in public schools, and sometimes in private schools as well. Students already have a fear of chemistry beforehand, and unfortunately, this 'chemistry phobia' does exist].

These social and physical conditions block the meaningful "bridge talk" that is needed for understanding, making students feel disconnected from the lesson.

Summary

The second research question in this study examined the factors that influence student engagement in chemistry classes through the focus of the student engagement framework (Bond et al., 2020). The data revealed that student involvement is a multidimensional concept, encompassing behavioral, affective, and cognitive domains. In the behavioral domain, while hands-on laboratory work remains the most powerful factors of engagement students to the chemistry subject, its implementation is not equal within the public and private school context. Public school students often have got not satisfactory experience in laboratory works, remaining passive during the laboratory works, while private school students have got an opportunity to feel the “science” deeply through actively involving to leboratory lessons. Furthermore, asking questions and consistent note-taking emerged as critical behavioral signs of engagement, serving as essential tools for students to manage the subject's high cognitive load. In the affective domain of, engagement is strongly sharpened by the emotional classroom climate. Positive affective drivers include facotrs such as trust in teacher support, the enjoyment in learning through games, , and the comfort of peer collaboration in that happens in "student language" to foster motivation and a sense of belonging while studying. In contrast, chemophobia and classroom distractions such as noise and disruptive behavior can reduce students’ emotional engagement and are able to lead to disengagement from learning. Finally, in the cognitive domain of engagement, the findings highlight that engagement is deepest when teachers provide "bridge talk" through the use of household language, everyday metaphors, and real-world links. These factors of enagement allow students to move beyond rote memorization of chemistry concepts toward meaningful conceptual processing of comlex concepts by connecting symbolic nature of chemistry subject to their daily life experiences. Overall, the findings demonstrate that student engagement is a dynamic process that is shaped by the interaction between pedagogical support, environmental conditions, and the student's own behavioral strategies for navigating the "conceptual struggle" and abstract nature of the subject.

Summary of the Chapter 4

The findings of this study showed that secondary school students in Azerbaijan describe chemistry subject as and abstract one with conceptual challenges and engagement conditions. The challenge in this subject rooted in the difficulty of navigating Johnstone's Triangle, specifically the disconnection between macroscopic observations and submicroscopic or symbolic representations. This challenge is intensified by a heavy reliance on mathematical reasoning, which is lead to psychological divide between "technical" and "humanitarian" learners. To compensate for these classroom difficulties, students utilize AI tools (for explanation), family support (informal bridge talk), and independent homework, which in the study was mentioned as a concept "Parallel Learning System". Regarding student engagement, findings revealed that, according to Bond et al. (2020) framework about students engagement in the lessons, involvement is shaped by several types of engagement like behavioral, affective, and cognitive factors. Overall, the study demonstrates that students' understanding and engagement are deeply interconnected, depending not only on the abstract nature of chemistry subject, but also on the quality of instructional scaffolding provided within the classroom and the informal support systems available at home.

CHAPTER 5: DISCUSSION

In chapter 4, the research on exploring secondary school students' experiences in learning chemistry indicated detailed findings on the given research questions:

1. How do students at secondary schools in Azerbaijan describe their experiences of learning chemistry?
2. What factors contribute to student engagement in chemistry classes?

The chapter 5 describes the alignment of study's findings with existing literature, focusing on the representational competence, student engagement, and learning across formal and informal contexts. To provide a comprehensive analysis of the data, this chapter evaluates the three primary themes that emerged from the research: the perception of learning chemistry as a process of conceptual struggle, the role of mathematical skills and technical topics as foundational challenges, and the development of a 'parallel learning system' which comprises dimensions like digital tools, family support, and independent homework as a critical compensatory structure. By situating these findings within Johnstone's Triangle (1982) and the student engagement framework, this discussion highlights how context-specific "student voices" from Baku both confirm and extend current global perspectives on chemistry education. The discussion chapter integrates the findings with existing literature, particularly focusing on representational competence, engagement, and learning across classroom, homework, digital contexts, and new findings with external literature that were not mentioned in the literature review part. The findings confirm both existing research and extend it by introducing context-specific insights grounded in students' voices.

Chemistry as Conceptual Struggle: Abstract Nature and Symbolic Language

The findings of this theme demonstrate that students perceive chemistry subject as abstract, difficult, and challenging because of symbolic language, particularly formulas and equations. Students' statements such as "I couldn't understand why I learn chemistry" (Student 4) and "formulas are very difficult" (Student 11) reflect a broader struggle of this subject, particularly to make deep understanding in chemistry concepts. These findings strongly align with Johnstone's triplet model (Johnstone, 1982, 1991), which explains that students struggle in linking between macroscopic, submicroscopic, and symbolic phenomena. Similarly, research demonstrates that students experience confusion when instructions are not given properly in order to bridge these three representations in understanding chemistry concepts (Taber, 2013; Talanquer, 2022). For example, studies from Sweden and Singapore demonstrate that quick transitions between representations in Johnstone's Triangle without explanation each step lead to surface understanding of chemistry concepts (Aksela & Boström, 2012; Chandrasegaran et al., 2007). Moreover, findings also confirm that symbolic overload, particularly formulas, reduces student engagement in chemistry subject. This finding is consistent with research showing that students perceive chemistry as "abstract" due to representational density rather than lack of ability to understand chemistry (Taber, 2013). Teachers' reports about symbolic overload support this idea, noting that students mostly lose their interest in chemistry lessons when formulas and calculations dominate in the chemistry concepts. However, literature in this study demonstrates that students do not simply describe chemistry as an abstract subject, they explicitly connect abstraction to their inability to see and relate concepts in chemistry to real life, reinforcing the importance of scaffolding in this step. Talanquer (2022) and Akesson Nilsson & Adbo (2024) say that students learn chemistry better when teachers make clear connections between the macro, micro, and submicro levels when they explain chemistry ideas.

Construction of Understanding in Chemistry Subject: “Parallel Learning System”

The findings of this theme demonstrate that students construct their understanding of chemistry not only through classroom instruction, but also through an external support, that named as a “parallel learning system”. Within this system, students use homework, digital tools, and seek helo from family members to develop and sharpen conceptual understanding in chemistry concepts besides the teacher’s explanation provided in lessons. Students consistently described homework as an essential component of learning chemistry, emphasizing that it helps reinforce concepts and provides additional time to process complex ideas. This findings of study aligns with research suggesting that homework helps students to better understand and process chemistry concepts and be meaningfully involved in learning (Hattie, 2009).

The role of family members considered as a vital component of the parallel learning system according to findings, where they act as informal facilitators who help to diminish the struggle with understanding the abstract parts of chemistry concepts and provide the "bridge talk", which is necessary for conceptual understanding. This type of interaction is close with the sociocultural theory, which indicates that learning is co-constructed through social interaction and guided support (Vygotsky, 1978). Besides the alignmnet of this findings with theory, empirical research demonstrates that parental support is a significant predictor of academic self-efficacy of students, fostering their confidence, which is needed for students’ involvement in coping with difficult scientific tasks and assignments (Teuber et al., 2022; Zuma, 2020). Moreover, autonomy-supportive involvement of parents, where they initiate constructive conversations and encourage their child to self-initiated learning creates a positive reciprocal relationship with academic achievement (Teuber et al., 2022). Furthermore, family attitudes toward chemistry subject can provide emotional support to students in their learning. Students are more likely to enjoy chemistry and develop a strong interest in STEM when the subject is valued at home, where family members play a crucial role, helping them avoid the negative opinions or “freak out” reactions often expressed by peers (Aminu, 2026; Dudley, 2026).This influence is not only emotional, but also structural. As students frequently discuss chemistry with their parents, and family opinions come a primary factor in their decision to enroll in chemistry programs in future (Aminu, 2026; Ugwo et al., 2024).

Findings about the usage of AI tools in this study revealed that students use AI tools, such as ChatGPT to support understanding of chemistry concepts, particularly when classroom explanations of chemistry concepts became insufficient to them to construct sharp understanding. Some students use AI tools for explanation, while other students use it for just copying answers, according to teachers' reports. Students’ and teachers’ reports about usage of AI tools in studying chemistry align with literature which indicates that digital tools can enhance learning when it is used with clear guidance (Mayer, 2009; Lee et al., 2021). However, teachers confessed some concern about passive use of AI tools, particularly copying answers or getting information without understanding its meaning. This reflects a growing tension in modern education between access to information and meaningful learning. Moreover, the findings in this study revealed the usage of digital tools in private schools during the chemistry lessons. According to the literature review, the study about the usage of digital tools, precisely virtual labs depicts that its effectiveness depends on how much the usage of digital tools are scaffolded and align with clear instructional goals (Nechypurenko et al., 2023; Rosli & Ishak, 2024).

Engagement Domains

Behavioral Domain of Engagement. The findings related to this engagement domain indicate that behavioral engagement is most prominent during active participation in laboratory sessions. This structure is supported by Bond et al. (2020), who describe active participation of students as an important part of behavioral engagement, and connected with Johnstone's (1982) idea, which indicates that students need to connect experiments with symbolic understanding. While practical work is a "reward" in some settings to manage behavior, the lack of hands-on access in public schools creates not meaningful engagement of students to laboratory works. Furthermore, behaviors like note-taking and asking questions are critical for managing cognitive load, and play a crucial role in improving focused learning of students (Lee et al., 2021).

Affective Domain of Engagement. Emotional classroom climate influences students' motivation toward the engagement in chemistry lessons. Positive drivers such as teacher personality and gamification align with literature, suggesting that these factors increase students' interest and enjoyment to the lesson. Moreover, the comfort of "student language" in peer groups reflects Vygotsky's (1978) sociocultural theory, indicating that learning through social interaction leads to affective engagement of students to the lessons. Conversely, "chemophobia" (fear of chemistry) and classroom noise act as significant affective barriers toward students' engagement to lessons. Noise as a negative affective domain has been shown in the research, which is done by Brill and Wang (2021), indicating that noise is able to lower achievement of students and increase cognitive tiredness.

Cognitive Domain of Engagement. Cognitive engagement of students to chemistry lessons is facilitated when teachers successfully bridge the gap between abstract nature of subject with real-world experience. The usage of household language and metaphors by teachers furing the lessons can lead to an effective scaffold for conceptual reasoning for students, helping them clearly navigate through Johnstone's Triangle (1982). Moreover, this finding is aligned with Talanquer (2022) and Akesson Nilsson & Adbo (2024) research, which emphasize that guided representational explanations can improve conceptual clarity of complex chemistry concepts. Students demonstrate the strongest cognitive engagement to the lessons when teachers via explanation reduce abstraction of chemistry concepts through real-world links and using metaphors, helping students to connect symbolic chemistry concepts to their own life experiences.

Moreover, the study indicates one more finding about teaching in chemistry highlighting that student engagement is much more influenced by understanding of concepts rather than simply doing activities during the chemistry lessons. While the literature often emphasizes about the importance of inquiry-based learning, practical work, and interactive activities in promoting engagement of students to the chemistry lessons (Urdanivia Alarcón et al., 2023), students in this study reported that lessons become more interesting when they understand the material, the primary link between engagement and understanding, highlighting the central role of cognitive engagement and meaning-making in chemistry learning (Bond et al., 2020; Talanquer, 2022). This finding refines existing engagement frameworks by emphasizing that the cognitive dimension of engagement is much more critical, rather than only behavioral participation of students during the lessons. Research defines engagement as a multidimensional factor that includes cognitive involvement in lessons alongside behavioral and emotional aspects (Fredricks et al., 2004). Therefore, this finding in study extends the literature via proposing the idea that conceptual clarity is a central factor of engagement in chemistry learning.

Environmental Factors

Beyond the factors for diverse types of engagement that were identified through findings, this study also revealed a significant "environmental dimension" that shapes students' conceptual understanding during the chemistry lessons. While much of the existing literature focuses on the representational difficulties described in Johnstone’s Triangle (1982), students in this study often linked their learning difficulties to environmental factors such as classroom noise, distractions, and difficulty concentrating during the lessons. This finding indicates that for Azerbaijani students, the struggle to learn chemistry is not only a mental process but also the process that heavily dependent on the social and physical conditions of the classroom. These observations of environmental factors are supported by research, which demonstrates that the classroom environment is a primary predictor of student engagement, attention span, and overall academic achievement (Hattie, 2009; Marzano, 2003). According to research, environmental noise can negatively affect reading comprehension and mathematical reasoning, because in noisy environment in classroom, students must use extra mental effort to ignore distracting sounds, which can lead to faster mental tiredness and students can make more mistakes in tasks (Nurmukhambet et al., 2025). Furthermore, children are far more vulnerable to disruptions than adults. According to Leist et al. (2022) and Seep et al. (2000), in classrooms with poor acoustics, students may fail to understand 25% or more of the words what their teacher speaks, because too much noise and echo can make teachers’ speech harder to understand. Similarly, acoording to Hurtig et al. (2016), too much noise and echo in the classroom can make difficult for children to remember words taught by teachers. In addition, international guidelines from the World Health Organization (1999) recommend that background noise in classrooms should not exceed 35 dB LAeq (LAeq is a measurement used to describe the average sound level over time based on human hearing in rooms) during teaching sessions to ensure that students can effectively extract and understand information and engage in meaningful learning.

Mathematical Barriers in Chemistry Learning

The last findings of this research is related to mathematical skills in chemistry learning which is the significant barrier in conceptual understanding of chemistry. Both students and teachers in this study identified mathematical topics in chemistry, such as balancing equations, the mole concept, and reaction rates, and described these topics as challenging ones to clearly understand chemistry topics because of a lack of mathematical skills. This idea is supported by literature which depicts that students while doing chemistry tasks with high mathematical content often show significantly lower initial performance (36% accuracy in chemistry tasks compared to 75% accuracy in non-math tasks in chemistry) (Koedinger et al., 2025). Conversely, another study contradicts the previous findings about usage of mathematical skills in chemistry lessons. According to Cai and Zhou (2022), students often struggle with mathematical topics in chemistry not because of lack of mathematical knowledge, but because students are challenge in transfering mathematical skills and knowledge to chemistry contexts, highlighting theexplicit need for instructional support, in order to balancing the mathematical skills with understanding of concepts in chemistry. These findings from study confirm and extend existing literature by demonstrating that while mathematical skills are strongly associated with chemistry performance, the real challenge can be the transferring mathematical knowledge to chemical contexts.

Conclusion

In conclusion, the findings of this study demonstrate that secondary school students' experiences in learning chemistry in Azerbaijan are shaped by classroom instruction and a secondary "parallel learning system" comprising homework, family support, and digital AI tools. As demonstrated through both student and teacher perspectives, learning chemistry is a gradual construction of understanding often hindered by a "conceptual struggle". This struggle is primarily rooted in the abstract nature of the subject and the cognitive demands of navigating Johnstone's Triangle which is considered as difficult coordination between macroscopic phenomena, submicroscopic particle models, and symbolic language. According to data analysis, students initially experience chemistry as a difficult and disconnected to real life subject. However, they develop conceptual clarity over time by utilizing some that got name "parallel learning system" to seek "bridge talk" from family members, use AI tools for personalized explanations, and engage in reflective homework to reinforce classroom lessons. This research further categorized engagement types according to Bond et al. (2020) framework, highlighting that behavioral engagement factors (note-taking, asking questions, participation in laboratory works), affective engagement drivers (teacher personality, gamification, and peer language as emotional support), and cognitive engagement factors (metaphors and real-world links) are all essential for involvement and engage students' interest to chemistry subject. Consequently, the findings emphasize the urgent need to bridge the gap between the intended curriculum and actual classroom experience by strengthening representational teaching and integrating digital tools with appropriate instructional guidance.

Implications

Implications for Research

As the data of study was discussed in relation to representational competence and student engagement frameworks, it means that students' experiences in learning chemistry are shaped not only by cognitive factors but also by classroom environment, clarity of instructions, and learning practices across different contexts. While existing literature has primarily focused on the challenges with abstract thinking and bridge between representational level in chemistry learning (Johnstone, 1982; Taber, 2013), this study revealed that besides the mentioned factors, students also explicitly mention that their understanding of chemistry subject depends on classroom conditions also, and students reported factors that prevent to their meaningful understanding of subject, such as noise, distraction, and lack of focus during the lessons. This finding extends beyond traditional chemistry education research and aligns with educational studies demonstrating that classroom environment significantly influences students' attention, engagement, and academic performance in subjects (Hattie, 2009; Marzano, 2003; Fredricks et al., 2004). Therefore, further research in this study should *explore* how the classroom environment during the lessons impacts the understanding of chemistry concepts, particularly this research should be done in lower-secondary classes (7th and 8th grades), where students firstly are introduced to abstract concepts in chemistry.

Another important finding of this study is the concept namely a "parallel learning system," which includes homework, support from family members, and the use of digital platforms such as AI tools. The findings indicate that students do not rely only on classroom instruction to construct understanding, but actively seek additional explanations and clarification through these external resources. While existing research suggests that supplementary learning can improve academic performance of students (Özalp & Kahveci, 2015), it has not sufficiently examined how these forms of support contribute to students' conceptual understanding of chemistry. According to findings, family members often act as informal tutors, helping their child by explaining complex ideas in more accessible language, moreover, AI tools give explanations that help students understand difficult concepts. This idea suggests that learning in chemistry is distributed across formal and informal contexts, rather than narrowed to the classroom explanations. Therefore, future research should focus on how these elements of the parallel learning system, particularly homework design, family-supported learning, and the pedagogical use of digital tools can be more intentionally aligned with instructional goals to support deeper conceptual understanding in chemistry.

Moreover, according to this research, there is a significant distinction between the chemistry lessons in private and public schools in terms of access to laboratory work, technology, and instructional approaches. While such inequalities are often discussed at a systemic level, there is limited qualitative research capturing students' lived experiences. Subsequently, further research in this study should be expanded by including more diverse school contexts, including rural areas, to examine how structural and resource-related factors in chemistry lessons influence students' engagement and understanding.

In addition, the findings in this study highlighted an "intention-experience gap" between the intended curriculum (which emphasizes inquiry and modeling) and the actual classroom experience, where students struggle with symbolic language of chemistry and rote memorization. Taking into consideration that teachers should have an ability to "bridge" macroscopic and submicroscopic levels while explaining chemistry concepts, and it is central for students better conceptual understanding, it would be beneficial to study teachers' professional development needs regarding Johnstone's triangle theory.

Implication for Practice

In this section recommendations for educators, schools, and policymakers are provided based on the findings of this study.

According to findings in this research, students identified classroom noise, disruption, and lack of discipline as significant barriers in understanding chemistry concepts and meaningful engagement to lessons. This situation indicates that improving classroom management during the lessons is essential for effective learning. Hattie (2009) and Marzano (2003) mentioned that, in classes, where classroom management is appropriately constructed, it has a positive influence on student engagement and academic achievement in a subject. Subsequently, it is recommended that schools should support teachers in developing strategies to create structured, focused, and supportive classroom environments.

Moreover, according to the findings, there is a big difference between private and public school students' involvement in hands-on learning, laboratory work. While private school students reported that they feel like "scientists" through hands-on work, public school students often have limited access to reagents and act as a passive observer during the laboratory lessons in chemistry. Therefore, it is proposed that the Ministry of Science and Education should prioritize not only the provision of laboratory equipment but also the systematic training of teachers on how to safely and effectively involve students in practical experiments rather than just demonstration to students.

Since students consistently described chemistry as an abstract subject due to its symbolic language, teachers should move away from traditional oral-heavy instructions.

Moreover, schools should encourage teachers to use visual aids, 3D simulations, and "bridge talk" that explicitly connects particle-level models to macroscopic observations. Providing teachers with ready-made, colorful visual resources (similar to those that are used in private sectors) could help to boost the interest and engagement to the subject and reduce "chemophobia" (fear of chemistry).

APPENDIX A

Interview Protocol for students

Dear Participant! I would like to thank you for participating in this interview. I am Malak Farajova, a master's student at ADA University in Teaching and Learning. I am conducting an interview about students' experiences in learning chemistry at secondary schools in Azerbaijan.

The aim of this study is to explore students' experiences while studying chemistry. The interview will last approximately 40 min. During this time you will be asked a few questions about the topic. The questions are open-ended, and you have got a right to choose to answer or skip the question. For accurate take of notes, I would like to audiorecord our conversation today and lately transcribe it. Once I will collect all the data that is needed, your identity will be masked via replacing your name with a pseudonym.

Please, take into consideration that your participation is voluntary and you can stop the conversation at any time if you feel uncomfortable. All information that you are going to share with me will be confidential and will be protected under pseudonyms. I kindly ask you to choose your pseudonym and if you do not, I will choose your pseudonym. If you agree, please sign the consent form.

Dialogue. Preliminary Interview Questions.

Opening / Background

1.Could you tell me a little about yourself as a student

2. Could you describe your experience with chemistry classes so far?

Experiences in Chemistry Lessons

3. Tell me about a recent chemistry lesson that you remember clearly. What was happening in the lesson?

4. When you learn something new in chemistry, what usually helps you to understand it better during the lesson?

5. Can you describe a time when chemistry was confusing for you in class? What was happening in this situation? How do you solve this problem? (probing)

Representations & Understanding

6. What are some materials in chemistry content that are challenging to you to understand the subject better?

7. Can you give an example of a lesson where usage of pictures, models, lab activities experiments, or real-life examples helped you understand a chemistry idea?

Engagement

8. What kinds of activities in chemistry lessons make you feel more involved?

9.Describe a moment where you were engaged in chemistry lessons? How did you participate?

10. Are there any moments in chemistry lessons when you feel less engaged? What are those moments like for you?

Homework, Tutoring, and Independent Study

11. Tell me about your experience in chemistry studying outside of school? Parents support, such as homework or tutoring.

12. Could you tell me how homework tasks affect your understanding of chemistry concepts?

Digital / Online Learning

13. Could you talk about your experience in using digital tools in chemistry lessons?

Closure

14. Is there anything that I have not asked and you would like to share about your experience in studying chemistry as a student?

At the end I would like to ask, whether you have any questions. Thank you for participating in the interview!

APPENDIX B

Interview Protocol for Teachers

Dear Participant! I would like to thank you for participating in this interview. I am Malak Farajova, a master's student at ADA University in Teaching and Learning. I am conducting an interview about students' experiences in learning chemistry at secondary schools in Azerbaijan.

The aim of this study is to explore students' experiences while studying chemistry. The interview will last approximately 40 min. During this time you will be asked a few questions about the topic. The questions are open-ended, and you have got a right to choose to answer or skip the question. For accurate take of notes, I would like to audiorecord our conversation today and lately transcribe it. Once I will collect all the data that is needed, your identity will be masked via replacing your name with a pseudonym.

Please, take into consideration that your participation is voluntary and you can stop the conversation at any time if you feel uncomfortable. All information that you are going to share with me will be confidential and will be protected under pseudonyms. I kindly ask you to choose your pseudonym and if you do not, I will choose your pseudonym. If you agree, please sign the consent form.

Background

1.Could you tell me about your background as a chemistry teacher?

2. How can you describe your experience in teaching secondary school students, precisely 7th and 8th grades?

Students' Experiences in Chemistry Lessons

3. Could you describe your daily chemistry lessons from your practice? How do students usually participate during the lesson?

4. When new chemistry concepts are introduced, how do students usually are engaged?

Representational Understanding

5. What are some teaching tools in chemistry that make a positive impact on lessons?

6. What students find difficult in chemistry lessons?

Student Engagement

7. Could you talk about the strategies that you think increase students' engagement in chemistry lessons?

8. What do you implement when students look distracted during chemistry lessons?

Homework, Tutoring, and Independent Study

9. To what extent students come to class prepared? What do you do to increase their engagement for doing their homeworks?

10. Do you students take additional support in chemistry lessons?

Digital and Practical Learning

11 How do you facilitate using digital tools in chemistry lessons?

12. How do students learn through actual experiments?

13. What can you say about students' inquiry activities, in practical work? How do you facilitate inquiry activities, practical works in chemistry lessons?

Closing

14. Is there anything else that I have not asked you about students' engagement or their learning experiences in chemistry?

At the end I would like to ask, whether you have any questions. Thank you for participating in the interview!

APPENDIX C

Consent Form for Parents/Guardians of Students and Student Assent Form

Dear parent/guardian and student,

This form is an invitation for a student to participate in a research study that explores students' experiences of learning chemistry at secondary schools in Azerbaijan. The study aims to understand what helps or makes it difficult for students to engage and understand chemistry, what their experience with homework, tutoring, online or digital learning related to this subject.

The study is conducted by Malak Farajova, a Master's student in the Teaching and Learning program at ADA University, School of Education, under the supervision of Dr. Jeyran Aghayeva.

The planned interview with the student will last approximately 15-20 minutes, and participant will be asked open-ended questions about the student's experiences of learning chemistry. Participation is completely voluntary. The student may skip any question or stop the interview at any time without any consequences.

With permission, the interview will be audio-recorded and later will be transcribed for accurate data analysis. The student's name and any identifying information will be replaced with a pseudonym to ensure confidentiality. All collected data will be used only for academic purposes as part of the Master's thesis, and access to the data will be accessible only to the researcher and supervisor.

This study involves no expected risks. The student may benefit from reflecting on their learning experiences and sharing their views about the chemistry subject. Every effort will be made to protect the student's privacy and confidentiality.

If you have any questions about this study, please contact Dr. Jeyran Aghayeva, Assistant Professor, ADA University, School of Education, Ahmadbey Aghaoglu str. 61, by phone number (012) 437 32 35, or email via jaghayeva@ada.edu.az.

Please review the statements below and sign if you agree:

Parental/Guardian Consent

"I give permission for my child to participate in this study. I understand that participation is voluntary and that my child may withdraw at any time without consequences. I also give permission for the interview to be audio-recorded for research purposes".

Parent/Guardian Signature: ____________________________

Name (Printed): __________________________________

Date: ____

Student Assent

"I understand that I am being asked to participate in a research interview. I know that I can stop at any time and if I do not have to answer any question or I do not want to answer. I agree to participate in this study"

Student Signature: ______________________________

Name (Printed): ______________________________

Date: ______________________________________

APPENDIX D

Consent Form for Teachers

Dear Participant,

You are invited to participate in research conducted by Malak Farajova, a Master's student in the Teaching and Learning program at ADA University, School of Education. The research happens under the supervision of Dr. Jeyran Aghayeva, and Assistant Professor, Education Management School of Education, ADA University. The research aims to explore students' experiences in learning chemistry at secondary schools in Azerbaijan. Your participation in this study will make a significant impact on research by determining factors that support or prevent student engagement and understanding of chemistry subject.

The planned interview with you will last approximately 30-40 minutes, and you will be asked a number of open-ended questions that are focused on your observations about students' engagement, understanding, and learning experiences in chemistry. Participation in this study is completely voluntary. During the interview, you have a right to choose to not answer any question or to withdraw from the research at any time without any consequences for you.

With your permission, the interview will be audio-recorded in order to ensure accurate data collection and effective analysis of it. The information from the interview with you will be kept confidential. During the analysis of data, your name will be replaced with a pseudonym and any personal details in transcripts and reports will be replaced with signs. The collected data from the interview will be accessible only for the researcher and the supervisor of the research. When data is analyzed and reported, the findings from the interview will be used strictly for academic purposes as part of the Master's thesis.

This study does not involve any expected risks. You may benefit from reflecting on your observations of students' learning experiences in chemistry. Every effort will be made to protect your privacy to the maximum. If you have any questions about the research, you can contact Dr. Jeyran Aghayeva, Assistant Professor at ADA University, Ahmadbey Aghaoglu str. 61, by phone number (012) 437 32 35, or email via jaghayeva@ada.edu.az.

Please read the statement below and sign if you agree to participate:

"I agree to participate in this study. I understand that my participation is voluntary and that I may withdraw at any time without consequences. I also agree to allow my interview to be audio-recorded for research purposes".

Signature: ____________________________

Name (Printed): ________________________

Date: ________________________________

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