Investigating the Integration of Chemistry Instruction with Other STEM Disciplines (Science, Technology, Engineering, and Mathematics)

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LIST OF TABLES

Table 2.3.2.1. Reliability Statistics of the Pre-test and Post-test (General secondary school)

Table 2.3.2.2. Reliability Statistics of the Pre-test and Post-test (Lyceum)

Table 2.3.2.3. Reliability Statistics of the Pre-test and Post-test (International School)

Table 2.3.3.1. Mean Ranks Assigned by Experts for Survey Validation Criteria

Table 2.3.3.2. Results of Kendall's Coefficient of Concordance Analysis

Table 3.1.1. Identified STEM instructional methods and activities with definitions (as used in this dissertation)

Table 3.1.2. Frequency and percentage of STEM instructional methods and activities in the analyzed studies

Table 3.2.1.1. ANCOVA Results for Post-Test Scores – General Secondary School

Table 3.2.1.2. Post Hoc Comparison of Experimental and Control Groups – General Secondary School

Table 3.2.2.1. ANCOVA Results for Post-Test Scores – Lyceum

Table 3.2.2.2. Post Hoc Comparison of Experimental and Control Groups – Lyceum

Table 3.2.3.1. ANCOVA Results for Post-Test Scores – International School

Table 3.2.3.2. Post Hoc Comparison of Experimental and Control Groups – International School

LIST OF FIGURES

Figure 3.1.1. Effective STEM instructional methods and activities identified through literature analysis

Figure 3.1.2. Percentage distribution of STEM instructional methods and activities in the analyzed studies

Figure 3.3.1. Students' level of understanding of STEM-integrated lessons

Figure 3.3.2. Impact of STEM-based lessons on students' interest in chemistry

Figure 3.3.3. Challenges experienced during STEM-integrated lessons

Figure 3.3.4. Students' preferred components of STEM-based lessons

LIST OF APPENDICS

Appendix 1. Research Articles Selected for Content Analysis and the Implementation of STEM Instructional Methods and Activities (2020–2025)

Appendix 2. Pre-test, Post-test and Assessment Tasks

Appendix 3. Student Reflective Feedback Survey and Expert Validation Results

Appendix 4. Sample STEM-Based Lesson Activities

Appendix 5. Assumptions Testing for ANCOVA Analysis

Appendix 6. Distribution of STEM Instructional Methods and Activities across the Analyzed Studies

Appendix 7. Descriptive Statistics of Pre-test and Post-test Scores

CONTENTS

INTRODUCTION 1
LITERATURE REVIEW 8
1.1 STEM education 8
1.2 Interdisciplinary approach in chemistry education 14
1.3. Teaching Methods of integrated STEM in chemistry 18
METHODOLOGY 28
2.1 Research Design 28
2.2 Sampling 29
2.3 Data collection 30
2.3.1 Qualitative data collection 30
2.3.2 Quantitative Data Collection 30
2.3.3 Reflective Feedback Survey Data Collection 41
2.4 Data Analysis 43
RESULTS 45
3.1 Results of Qualitative Analysis (RQ1) 45
3.2 Results of Quantitative Analysis (RQ2) 50
3.2.1 Results from the General Secondary School 51
3.2.2 Results from the Lyceum 52
3.2.3 Results from the International School 53
3.3 Results of Reflective Feedback Survey (RQ3) 55
DISCUSSION 58
4.1 STEM Integration Methods and Trends in Chemistry Education 58
4.2 Impact of STEM-Integrated Instruction on Students' Learning Outcomes and Engagement 60
4.3 Students' Challenges and Perceptions of STEM-Integrated Instruction 62
CONCLUSION 67
LIMITATIONS 69
REFERENCES 70
APPENDICES 80

LIST OF ABBREVIATIONS

STEM - Science, Technology, Engineering, and Mathematics

AR - Augmented Reality

VR - Virtual Reality

PBL - Project-Based Learning

ICT - Information and Communication Technologies

SD - Standard Deviation

ABSTRACT

This study investigates the effectiveness of integrated STEM approaches in chemistry education and examines commonly used instructional methods in STEM-integrated chemistry teaching. A mixed-methods research design combining qualitative and quantitative approaches was employed. In the qualitative phase, 30 scientific articles published between 2020 and 2025 were analyzed to identify current trends and instructional practices in STEM-based chemistry education. The analysis revealed that project-based learning, inquiry-based instruction, engineering-based tasks, laboratory experiments, interdisciplinary activities, and digital technologies were among the most frequently applied methods. For the quantitive stage of research, 123 ninth grade students from three educational institutions located in Almaty, Kazakhstan participated. Findings revealed that STEM-related pedagogical practices improved the performance of students in academic work and increased their level of engagement and problem-solving skills. Thus, it is vital to mention the importance of student-centered learning in modern chemistry education.

Keywords: *STEM education, chemistry education, engineering design, instructional methods, interdisciplinary learning.*

АҢДАТПА

Бұл зерттеу химияны оқытудағы интеграцияланған STEM тәсілдерінің тиімділігін және STEM-интеграцияланған химия сабақтарында қолданылатын оқыту әдістерін зерттеуге арналған. Зерттеуде сапалық және сандық тәсілдерді біріктіретін аралас зерттеу әдіснамасы қолданылды. Сапалық кезеңде 2020–2025 жылдар аралығында жарияланған 30 ғылыми мақала талданып, STEM негізіндегі химия білім беруіндегі қазіргі үрдістер мен оқыту тәжірибелері анықталды. Талдау нәтижесінде жобалық оқыту, зерттеушілік оқыту, инженерлік бағыттағы тапсырмалар, зертханалық жұмыстар, пәнаралық әрекеттер және цифрлық технологиялар ең жиі қолданылатын әдістердің қатарына жататыны анықталды. Зерттеудің сандық кезеңіне Алматы қаласындағы үш мектептің 123 тоғызыншы сынып оқушысы қатысты. Зерттеу нәтижелері STEM-интеграцияланған оқытудың оқушылардың оқу жетістіктеріне, қызығушылығына, сыни ойлауына және мәселе шешу дағдыларына оң әсер ететінін көрсетті. Зерттеу қазіргі химия білім беруінде оқушыға бағытталған және тәжірибеге негізделген оқытудың маңыздылығын айқындайды.

Кілт сөздер: *STEM-білім беру, химияны оқыту, инженерлік жобалау, оқыту әдістері, пәнаралық оқыту.*

АННОТАЦИЯ

Данное исследование посвящено изучению эффективности интегрированных STEM-подходов в обучении химии, а также анализу методов обучения, применяемых в STEM-интегрированном преподавании химии. В исследовании использовался смешанный метод, объединяющий качественный и количественный подходы. На качественном этапе были проанализированы 30 научных статей, опубликованных в период с 2020 по 2025 годы, с целью выявления современных тенденций и педагогических практик в STEM-ориентированном химическом образовании. Анализ показал, что наиболее часто применяются проектное обучение, исследовательское обучение, инженерно-ориентированные задания, лабораторные работы, междисциплинарные виды деятельности и цифровые технологии. Количественный этап исследования охватил 123 учащихся девятых классов трёх школ города Алматы. Результаты исследования показали, что STEM-интегрированное обучение положительно влияет на академическую успеваемость учащихся, их вовлечённость, критическое мышление и навыки решения проблем. Исследование подчёркивает важность ученико-ориентированного и практико-ориентированного обучения в современном химическом образовании.

Ключевые слова: *STEM-образование, обучение химии, инженерное проектирование, методы обучения, междисциплинарное обучение.*

INTRODUCTION

In today's environment, education faces the problem of preparing individuals to solve complicated problems related to society, technology, and the environment. Some of these problems are beyond the scope of a single subject or a field of study in academia. Problems like global warming, sustainable management of resources, public health concerns, and technological advancements are examples of issues which cannot be understood without having an interdisciplinary perspective and ability to integrate concepts from different subjects or disciplines (Doğru, 2023).

Background of the Study

The rapid advancement of science and technology in the 21st century has fundamentally transformed the demands placed on educational systems worldwide. Governments and institutions have increasingly recognized that equipping students with interdisciplinary knowledge is essential for addressing complex global challenges (Thibaut et al., 2018). In response to these demands, STEM education — encompassing Science, Technology, Engineering, and Mathematics — has emerged as a globally influential educational paradigm that promotes integrated, problem-based, and inquiry-driven learning (Kelley & Knowles, 2016).

Within STEM education, chemistry occupies a unique and central position due to its inherent connections with all other STEM disciplines. Chemical principles underpin engineering processes, inform biological and environmental sciences, and rely heavily on mathematical reasoning (Brown et al., 2017). Despite these natural intersections, chemistry instruction has historically been delivered in isolation, with limited emphasis on interdisciplinary connections or real-world applications. This disciplinary fragmentation reduces student motivation and fails to adequately prepare learners for the complexity of contemporary scientific and professional environments (Margot & Kettler, 2019).

In the context of Kazakhstan, educational reforms under the updated national curriculum have placed increasing emphasis on interdisciplinary learning and the development of 21st-century competencies, including critical thinking, collaboration,

and problem-solving (Kusainova et al., 2023). Nevertheless, empirical research examining the integration of chemistry with other STEM disciplines — particularly within the Kazakhstan educational context — remains limited (Ozhibayeva & Nurmuhanbetova, 2021), underscoring the need for systematic investigation into effective STEM integration practices and their outcomes.

Statement of the Problem

Although STEM education has received considerable scholarly attention over the past decade, the majority of existing research focuses on general STEM integration without addressing the specific challenges and opportunities associated with chemistry as a discipline. Chemistry instruction continues to be taught predominantly through traditional, discipline-specific methods that prioritize content transmission over interdisciplinary application and student engagement (Margot & Kettler, 2019). As a result, students frequently struggle to perceive the relevance of chemistry to other fields and to real-world problems, leading to diminished motivation and lower academic performance (Doğru, 2023).

Furthermore, while a growing body of literature explores STEM integration in secondary education broadly, there is a notable scarcity of studies that empirically examine which specific instructional methods are most effective for integrating chemistry with other STEM disciplines, and how such integration affects students' learning outcomes and engagement — particularly in the Central Asian educational context (Kusainova et al., 2023; Ozhibayeva & Nurmuhanbetova, 2021). This gap in the literature constitutes a significant problem, as educational practitioners and policymakers lack sufficient evidence-based guidance to design and implement effective STEM-integrated chemistry curricula (Li et al., 2020).

Research Hypothesis

Alternative hypothesis: Students who receive STEM-integrated chemistry instruction will demonstrate significantly higher post-test scores compared to students who receive traditional chemistry instruction, after controlling for pre-test performance.

Null hypothesis: There will be no statistically significant difference in post-test scores between students who receive STEM-integrated chemistry instruction and those who receive traditional chemistry instruction, after controlling for pre-test performance.

Research Contribution

This study makes several noteworthy contributions to the field of chemistry and STEM education. First, it provides a systematic analysis of STEM instructional methods employed in chemistry education, drawing on 30 peer-reviewed articles published between 2020 and 2025, thereby offering an up-to-date synthesis of current trends and practices (Li et al., 2020; Thibaut et al., 2018). Second, the study contributes empirical evidence regarding the effectiveness of STEM-integrated instruction on students' academic performance and engagement across three distinct educational settings in Kazakhstan — a general secondary school, a lyceum, and an international school — thus capturing a range of institutional contexts rarely examined within a single study (Kusainova et al., 2023; Ozhibayeva & Nurmuhanbetova, 2021). Third, the findings provide actionable, context-specific recommendations for chemistry teachers, curriculum developers, and educational policymakers in Kazakhstan seeking to align instructional practice with the interdisciplinary goals of the national updated curriculum. Finally, by integrating qualitative content analysis with a quasi-experimental quantitative design, the study contributes methodologically to a field where mixed-methods approaches in chemistry-specific STEM research remain underrepresented (Fitriyana et al., 2024; Doğru, 2023).

Integrated STEM education, in contrast to these trends, has become a popular concept which stresses the integration of STEM subjects through relevant learning experiences. In general, integrated STEM education stresses the illustration of connections between the fields of STEM via the use of practical problem-oriented lessons which include elements of inquiry-based learning, collaboration, and engineering design approaches (Thibaut et al., 2018). According to findings, integration allows learners to utilize knowledge gained from several fields at once to

deepen their understanding of concepts and promote motivation to learn. Integrated STEM education allows learners to solve complex problems rather than discipline-based problems; therefore, it promotes skills that are necessary for solving real-world problems and is reflective of how knowledge is used in real-life situations (Thibaut et al., 2018).

Modern technologies such as artificial intelligence and big data are actively changing science and education, accelerating scientific discoveries and transforming approaches to learning. In the context of the dynamic development of the world, the field of education is also undergoing significant changes. Special attention is paid to key academic areas — science, mathematics, technology and engineering, which in modern realities are combined under the general term STEM (science, technology, engineering, and mathematics) (Kusainova et al., 2023).

All this meets the requirements of the updated educational content of the Republic of Kazakhstan. One of the key principles of this program is the study of individual subjects of the school curriculum in integration with other disciplines, which implies the active introduction of interdisciplinary connections, especially within the framework of the natural science cycle (chemistry, biology, geography, mathematics, computer science). This approach promotes the perception of chemistry not as a separate discipline, but in combination with other academic subjects, which makes the learning process more holistic. The integration of natural science disciplines plays an important role in shaping a scientific world view and a holistic picture of the world (Kusainova et al., 2023).

The interdisciplinary approach in education is the combination of knowledge and methods from various disciplines to solve complex problems and form a holistic worldview. It plays a key role in the development of critical thinking, analytical abilities and creativity, which is especially important in the context of rapid technological progress. Thanks to this approach, students not only learn disparate facts, but also learn to see the connections between different fields of knowledge and apply them in practice.

Integrated STEM education is an approach that combines four disciplines—science, technology, engineering, and mathematics—into cohesive lessons or units based on the connections between these disciplines and real-world problems. In this context, STEM integration involves students engaging in engineering design processes to develop technological solutions, requiring meaningful learning through the integration and application of mathematics and the natural sciences (Fitriyana et al., 2024). The integration of STEM education is an essential element when preparing learners to solve real-life problems through a combination of skills and critical thinking across various disciplines. STEM education is crucial in developing problem-solving skills and innovation among other important abilities in learners. With the integration of STEM education in instruction, learners can apply learned theories to practice.

In addition to that, this type of methodology encourages cooperation since students usually work in teams to come up with solutions for problems that may arise. It is a method that bridges the gap between theoretical studies and real-life situations (Fitriyana et al., 2024; Kusainova et al., 2023; Doğru, 2023).

In many cases, chemistry is referred to as the "central science" due to its crucial role as a common denominator in linking diverse fields of STEM education. Chemistry is connected with technologies, engineering, and mathematics, with an understanding of chemical reactions being important for the development of new materials in engineering and a significant portion of chemistry being quantitative and based on mathematics. However, although there are evident connections between chemistry and other STEM subjects, the way how chemistry is traditionally taught can be considered too isolated, with no particular attention being paid to practical applications that can increase students' motivation. The connection between chemistry and other STEM subjects not only contributes to improved performance in class, but also makes education more exciting and interesting for students. Understanding of the practical value of what one studies in class, like developing sustainable energy sources or improving medical technologies or crop yields, helps maintain long-term interests in chemistry and other STEM subjects (Brown, LeMay, Bursten, & Murphy, 2017).

Chemistry education within the broader context of other STEM subjects is a novel way of engaging students in their studies. The focus of this project differs from previous general researches on STEM education in that it highlights particular ways of making chemistry interesting for students in their everyday life by means of discussing such practical areas as sustainable energy, healthcare applications, and agricultural development.

This research paper is concerned with particular approaches and teaching methodologies for promoting interdisciplinary studies, rather than general theories. In addition, the paper provides detailed coverage of practical aspects of lab work, project-based learning, and experiments, which have not yet been given enough attention by today's scholars.

Yet another distinctive feature of this study is the emphasis placed on fostering 21st century skills including problem-solving, creativity, collaboration, and adaptability. While conventional learning in chemistry mainly concentrates on imparting knowledge and achieving success, this research puts great attention to life skills that can be developed using STEM learning techniques.

Furthermore, the research utilizes a comparative study of the effects of conventional chemistry education compared to STEM education methods, based on the pre-test and post-test evaluation, alongside student feedback. This approach allows for an insight into the role that STEM plays in education from a quantitative perspective.

Aim of the Research: the aim of this research is to investigate the integration of chemistry instruction with other STEM disciplines (Science, Technology, Engineering, and Mathematics) by identifying commonly used STEM integration methods and examining their impact on students' learning outcomes and engagement.

Objectives of research:

- To identify and analyze STEM integration methods used in chemistry instruction and to determine current research trends in chemistry education;
- To examine the impact of commonly used STEM integration methods on students' learning outcomes and engagement in chemistry lessons;

- To explore students' perceptions of STEM-integrated chemistry instruction and identify the challenges they face in school classrooms.

Research Questions:

1. What STEM integration methods are used in chemistry instruction, and what trends can be identified in chemistry education research?
2. What impact do commonly used STEM integration methods have on students' learning outcomes and engagement?
3. What challenges do students face, and how do they perceive STEM-integrated chemistry instruction in school classrooms?

Significance of the Study

The present study is important to the emerging field of interdisciplinary chemistry education because it explores some common ways to integrate STEM disciplines into teaching practice, as well as analyzes the results of their application to improve students' academic performance, increase engagement in the subject, and change their attitudes towards chemistry lessons. The information provided by the research gives an idea about the efficiency of using science, technology, engineering, and mathematics when teaching chemistry and helps in implementing interdisciplinary approaches to science education. In addition, the project reflects current trends in Kazakhstan educational policy that emphasize interdisciplinary knowledge, critical thinking skills, problem-solving, teamwork, and the development of other 21st-century competences among students. Thus, through literature analysis, practical implementation in classrooms, and student assessments, the research allows gaining insights into the benefits and difficulties of interdisciplinary STEM teaching in general and chemistry classes specifically.

LITERATURE REVIEW

1.1 STEM education

Over the past decade or so, it has been widely recognized that STEM education plays an important role in preparing learners for the realities of the 21st century. Numerous studies have been conducted on several aspects of STEM education, such as curriculum development, teacher training, and learner achievements.

Kelley and Knowles (2016) carried out an important study entitled “A Conceptual Framework for Integrated STEM Education,” whose objective was to create a theoretical model that would help design integrated STEM lessons. Using a conceptual research design based on a literature review approach, Kelley and Knowles (2016) focused on educational methods associated with each of the four fields: science, technology, engineering, and mathematics. The key finding of their research is the creation of a framework based on interdisciplinarity, problem-solving, and design. Kelley and Knowles (2016) claim that true integration is possible only through the deliberate connection between disciplines. Therefore, their study creates an important theoretical basis for understanding how multidisciplinary, interdisciplinary, and integrated education differ from one another.

The paper stresses the importance of designing learning contexts where problems and their complex nature will be mirrored, and where students will engage in solving these problems by inquiry and design processes. The authors advocate for designing such an integrated framework where engineering will become the key concept uniting theory and practice. Consequently, students should move across different disciplines on purpose; this will be achieved not only on theoretical level but also in terms of educational process. In the course of time, this concept was used as one of the main references in STEM education studies, becoming the basis for educational methods and practices.

Thibaut et al. (2018) make a significant contribution in their article, titled "Integrated STEM education: A systematic review of instructional practices in secondary education." Thibaut et al.'s research aimed at identifying instructional

practices widely used in the field of integrated STEM education. To conduct this systematic literature review, the researchers examined 43 peer-reviewed studies published between 2005 and 2016, focusing specifically on instructional practices in secondary education. The findings of this study reveal that problem-based learning, inquiry-based teaching, engineering design activities, and real-world activities were the instructional practices most commonly used in STEM teaching. In their conclusions, the researchers state that integrated STEM education is most effective when it leads to inquiry-based learning and is based on real-life problems.

In addition, the review stresses that the successful integration of STEM instruction requires not just incorporating integrated instruction content, but the alignment between instructional goals, instructional methods, and assessment techniques as well. It emphasizes the importance of integrating curricular design with interdisciplinary approach along with facilitating cooperation between educators belonging to different disciplines. In addition, the role of teachers is changed from mere transmitters of information to facilitators of inquiry. Moreover, the findings of the study lay down an excellent empirical foundation for identifying features of quality STEM integration and contributing to developing a shared language of discussion for instructional approaches used in STEM education.

A study by Margot and Kettler (2019), named “Teachers’ perception of STEM integration and education”, aimed at exploring teachers’ perspectives on the integration of STEM education and issues related to it. The review included results derived from 40 different studies, paying attention to teachers' attitudes, experiences, and views regarding STEM education. It appears that while many teachers have positive perceptions towards STEM integration, a large number of them lack preparation skills to integrate STEM subjects in their classrooms due to inadequate training, shortage of funds, and insufficient support from management.

According to the research, one of the major barriers to proper integration of STEM lies in the fact that there is very little provision of teacher training programs that provide educators with necessary knowledge in specific disciplines as well as

pedagogical skills for interdisciplinary teaching. Moreover, a significant proportion of teachers surveyed also stated that there was not enough time allocated to create interdisciplinary curricula, along with lack of instructional materials and support for experimental approaches. As far as possible solutions to such issues are concerned, Margot and Kettler believe that professional development programs should go beyond simply presenting information in order to involve curriculum development, mentoring, and reflective teaching. It is important to note that according to these researchers, the key to successful implementation of integrated STEM instruction lies in systemic support offered to educators.

Another study conducted by Li et al. (2020) entitled "Research and trends in STEM education: A systematic review" investigated the current trends and future perspectives in STEM education. This study sought to provide a synthesis of new themes, methods, and pedagogical approaches in STEM research. A systematic review methodology was applied in analyzing peer-reviewed papers in prominent education journals spanning the period from 2000 to 2019. The unit of analysis for the present study was scholarship relevant to STEM education. The results showed that there is a growing trend towards promoting inquiry learning, technology-based teaching, interdisciplinarity, and equal opportunity in STEM education. According to Li et al., STEM education has moved away from being concerned solely with technical skills to emphasizing critical thinking, creativity, and practicality.

From this study, the following trends have been observed to significantly affect STEM learning in the contemporary society. First, there is an increasing trend in the use of inquiry-based learning methodologies whereby learners are required to pose questions, conduct investigations, and construct knowledge through their exploration processes. Secondly, there has been a great need for the adoption of digitally based learning, which has increasingly featured in the research articles reviewed through simulation, coding, and augmented reality learning environments.

Moreover, Li et al. found an increasing focus on interdisciplinary approaches to curriculum design, with scientists urging for the flawless integration of science,

technology, engineering, and math to address issues related to interdependent aspects of real-life situations. Significantly, the study of Li et al. also brought out another important issue that is receiving increasing attention, and that is the matter of access and equality.

According to the authors, there is an emerging paradigm shift from focusing on technical skills alone to a wider scope of learning outcomes within STEM. These learning goals include critical thinking, creativity, collaboration, and practical application, which form the key aspects identified by the authors as the cornerstone of STEM literacy in the contemporary era. The need for pedagogies that are flexible and dynamic is highlighted to meet the needs of learners in today's changing technological environment.

The current studies also show the importance of inquiry-based learning as well as an interdisciplinary approach to the subject. One of these studies was conducted by Chiu et al. (2023), who used mixed methodology in the research named "Community-based STEM learning and its effect on student identity development." The study aimed to investigate the effect of STEM learning settings on student participation and self-image. The research involved surveys and interviews of secondary school students participating in STEM-related activities in their communities. It was concentrated on the development of student identity and motivation.

The main emphasis of the research is on the issue of identity development and the motivational pathway of students concerning their engagement in STEM-related activities. The research showed that students whose learning experiences were autonomy supportive—where there was freedom of choice, relevance, and ownership of the process of learning—showed significantly higher levels of interest for STEM career options and increased intrinsic motivation, as well as a more positive self-concept as capable science learners. Importantly, those students who worked on interdisciplinary social projects were found to be more engaged.

As stated by Chiu et al., the integration of community-based approaches to STEM education helps students to better understand the real-world relevance of

knowledge while at the same time building a stronger sense of identity and belonging to the field. This study presents ample support for the use of learner-centric and inquiry-based teaching approaches in STEM education, especially programs geared toward sustained involvement.

A growing understanding of the role technology can play in STEM education has emerged recently. One such paper that discusses this aspect is Ibáñez and Delgado-Kloos's (2018) "Augmented Reality for STEM Learning: A Systematic Review." In the study, the researchers seek to investigate the use of AR technologies in STEM education as well as its effects on the learning outcomes of students. Specifically, the authors review a wide variety of empirical papers from a number of STEM subjects with a concentration on the process of learning through the application of AR technologies. The object of research is comprised of students participating in AR-assisted STEM education programs, especially in physics and chemistry.

By means of a systematic review of studies that were either experimental or quasi-experimental, the authors examined various aspects related to interventions using augmented reality (AR). The intervention allowed learners to visualize the various phenomena including trajectories of motion, vectors, molecular structures, and processes through interactive simulations. Performance tests, mapping activities, and learner feedback often featured in the studied interventions and, hence, enabled researchers to conduct analyses of both cognitive and affective effects. It was revealed that the utilization of AR significantly improved students' spatial skills, conceptual knowledge, as well as their motivation and interest in science-related subjects. Furthermore, the learners performed more accurately when it came to expressing and applying scientific concepts.

In summary, the review highlights the benefits associated with the use of AR in STEM education. Learners who struggled in understanding abstract or invisible concepts have been able to make significant strides in terms of comprehension through the use of visual and interactive tools. According to Ibáñez and Delgado-Kloos, the use of AR in an appropriately designed educational framework would help in fostering

personalized and differentiated learning while successfully making the link between theory and practice. The review adds to a growing body of literature on the use of technology in facilitating STEM education, specifically with regards to disciplines like chemistry and physics.

"Effects of an Engineering-Related STEM Curriculum on Students' Achievement in Science and Mathematics," a quasi-experimental research by Radloff & Guzey, explores the impact of an engineering-related STEM curriculum on student achievement in key scientific areas. This research was conducted with the purpose of identifying the way an engineering-related STEM curriculum affects the students' academic achievement levels through a comparison between test and control groups before and after instruction. Participants of the study included students taking part in STEM-related programs. It has been found that the test group had much higher achievements in science and mathematics compared to control-group students who received standard education.

The students who underwent the STEM-based program showed considerable progress compared to those who were subjected to traditional forms of instruction. The STEM-based program emphasized the importance of design and application-oriented problems that led to better understanding and increased motivation among students. Furthermore, the program focused on developing thinking skills and teamwork, which is vital for integrated STEM learning.

In conclusion, according to the researchers, the inclusion of engineering into STEM education, particularly when delivered using hands-on, problem-solving activities, results in clear benefits in interdisciplinary knowledge and skill application among learners.

Another study conducted by Wieselmann et al. (2022), titled "Analysis of Integrated STEM Curriculum Units Developed by Teachers: Focusing on Coherence and Clarity of Instruction," analyzed STEM curriculum units designed by in-service teachers. Their objective was to group the types of instructional techniques found in 15 STEM curriculum units. Using content analysis, the authors found that the most

successful units included inquiry-based instruction, engineering design, and theme-based multi-discipline integration. They noted that coherence and clarity of interdisciplinary instruction are necessary for effective STEM learning and engagement.

With the development of knowledge related to the concept of integrated STEM learning, there is a focus on how these interdisciplinary techniques should be applied effectively in specific disciplines. There are many ways in which chemistry education can incorporate the interdisciplinary aspect of STEM in order to improve teaching and learning outcomes in this discipline. This will be explored in detail in the following section.

1.2 Interdisciplinary approach in chemistry education

Development of interdisciplinary skills has become a core objective in modern STEM education, especially chemistry education. Since the nature of chemistry allows the field to overlap with numerous areas, such as physics, biology, engineering, environmental science, and math, interdisciplinary learning in chemistry education becomes vital rather than desirable. An interdisciplinary approach to chemistry education is indispensable when it comes to developing skills needed to understand complex issues and use chemistry skills outside the classroom environment.

Generally, chemistry lessons cover various themes including thermodynamics, chemical kinetics, molecular biology, and materials science, all of which need a good command of concepts learned from several different areas of knowledge. As mentioned by Pleasants and Olson (2019) in their study, "Teachers' Use of Interdisciplinary STEM Activities: An Exploratory Multiple Case Study", "Interdisciplinary STEM instruction involves more than just integrating the subject matter; rather, interdisciplinary instruction requires creating authentic learning experiences that span across the traditional discipline." Utilizing qualitative multiple-case studies methods, Pleasants and Olson analyzed how secondary teachers create and conduct interdisciplinary STEM activities. The study was focused specifically on the instructional practices of STEM schools. The results showed that effective teaching involved making cross-

subject connections and involving colleagues from other areas of expertise in developing tasks for students. According to Pleasants and Olson, interdisciplinary real-life projects, combining physics (energy conversions) and/or biology (biochemistry), have a positive effect on students' performance in chemistry lessons.

In the context of interdisciplinary education in the natural sciences, A. Dyachenko (2024) examines the effect of cross-disciplinary approaches on students' perception of science in the paper "Integration of interdisciplinary connections between chemistry, physics and biology in secondary education." The author explores the effect and efficacy of interdisciplinary connections in secondary education, especially with respect to chemistry and physics classes, using such research tools as generalization, surveying, and theory construction to investigate how the integration of multiple scientific fields affects students' cognition.

As per the findings, students develop a greater and more systematic comprehension of both the subjects by considering the chemical processes in terms of physics such as the transformation of energy, motion of molecules, and reactions. It is clear from the fact that interdisciplinary learning allows the students to realize the interrelationship among different scientific principles and utilize their learning in practical situations. This ultimately helps the students enhance their performances both academically and intellectually.

This research also suggests that an interdisciplinary approach to education, where projects play a central role, significantly improves critical thinking skills, creative thinking, and collaboration among students. About 90 percent of students enrolled in an integrated learning program showed an increased ability to think across various subjects, work in teams, and use scientific thinking for real-world applications. An integrated learning environment inspires students to move beyond individual subjects and see science as one whole discipline.

Significantly, the necessity of the readiness of the teachers and institutional support in implementing interdisciplinary instruction was highlighted by Dyachenko. Teacher readiness to work in collaboration and to integrate teaching techniques has

been noted as a major difficulty in this research. However, when proper support is provided, interdisciplinary approach benefits students in understanding and motivating them, and also helps in forming a scientific outlook whereby they realize that everything in the world is interrelated scientifically.

All of these results further emphasize the growing body of research from across the globe which shows that interdisciplinary STEM education plays an absolutely necessary role in developing knowledge and skills required in today's society.

Interdisciplinary STEM project-based learning is emphasized by Han, Kelley, and Knowles (2022), in their paper entitled "Sustaining Interdisciplinary STEM Instruction: Challenges and Opportunities." They undertook a case study of educators who have participated in professional development workshops regarding interdisciplinary teaching in STEM subjects before. Their research findings suggest that interdisciplinary education may lead to better academic achievement and increased engagement from students, but sustaining such instruction becomes difficult without institutional backing, collaborative opportunities, and interdisciplinary instructional resources. In the field of chemistry education, Han et al. note that incorporating environmental engineering (such as water filtration) or biotechnology applications (genetic engineering) in projects allows students to use their chemical knowledge in practical situations.

Moreover, the study emphasized the need for the integration of interdisciplinary education in accordance with the country's curriculum and assessment framework. The researchers found out that while teachers expressed a great willingness to incorporate interdisciplinary teaching, many challenges often hindered them, particularly rigid schedules and limited chances for collaboration. According to Han et al., it is important for schools to adopt flexible school systems, establish teacher communities, and offer continuous professional training in order to maintain high-quality interdisciplinary teaching, particularly complex disciplines like chemistry.

Just like other nations, Chiu et al. (2023) highlighted the benefits associated with interdisciplinary learning through their study titled "Community-Based STEM

Learning and Its Impact on Student Identity Formation." By combining survey data and interviews conducted among secondary-level students who were undertaking STEM projects in the community setting, the researchers noted that integrating aspects of chemistry to solve social issues such as environmental sustainability and health helped improve motivation, increase engagement, and foster identification with the sciences among participants. According to the authors, besides boosting the conceptual understanding of the subjects, inter-disciplinary activities played a key role in determining academic interests.

Moreover, the adoption of digital tools in multidisciplinary approaches to teaching chemistry has brought about novel ways of improving student learning. This is addressed by the research by Li et al. (2024), titled "Integrating Augmented Reality into STEM Lessons on Kinematics and Mathematics," which has broader applicability to the field of chemistry too. As shown in this design-based research, the use of augmented reality (AR) tools has significantly improved student spatial reasoning, visualization capabilities, and participation in inquiry-based exercises. In terms of chemistry, the ability to visualize molecular structures, chemical reactions, or atomic models through AR can be an effective way of bridging disciplines and making scientific concepts more relatable.

A very useful approach in interdisciplinary chemistry education comes from recent studies analyzing how effective the use of STEM integrated learning can be in secondary schools. For example, Dibyantini et al. (2023) have investigated the use of STEM integrated project-based learning in teaching chemistry, particularly focusing on improving students' scientific literacy and motivation for learning. The analysis conducted in their study included real classroom practices where students were introduced to realistic problems such as environment investigation, water testing, and development of sustainable products. In all these activities, students had to use not only chemical principles but also biological and technological ones.

It is evident from the findings that use of practical and problem-solving activities for teaching chemistry has a great impact on improving students’ involvement, critical

thinking skills, and level of understanding. It has been found that the motivation for learning has increased among students because they viewed chemistry not as an independent subject, but as a tool used to solve societal issues.

Furthermore, research shows that effective teaching of interdisciplinary chemistry requires both content integration and proper design of coherent learning environment. According to Wieselmann et al., effective STEM education curriculum is comprised of inquiry-based learning activities, design elements of engineering, and interconnections among subjects. This allows for active involvement of learners in the learning process and helps develop critical thinking. Moreover, just as in the case of STEM curricula, Dare et al. (2021) suggest that authentic tasks and clear connections among disciplines should be involved in the curriculum design to ensure meaningful learning.

The other important aspect that emerges time and again in most research studies is that of the importance of teacher assistance and instruction itself. Since interdisciplinary instruction demands a certain level of preparation, curricular alignment, and availability of appropriate teaching material, it becomes necessary for teachers to have methods by which they can plan lessons in a way that integrates chemistry with other subject areas. Without this, it would become very difficult for any interdisciplinary approach to yield the desired results.

A number of recurring themes can be seen from the analyzed studies. Disciplinary integration into chemistry teaching is important, and it has to incorporate elements such as content integration, use of problem contexts from life, student involvement through inquiry/project based learning approaches, and collaboration on the part of the teachers. Chemistry becomes more understandable to students when its interconnections with other subjects become evident. In addition, by making the connections between chemistry and other sciences or life in general, the student is able to make use of the concepts learned in real life situations.

1.3. Teaching Methods of integrated STEM in chemistry

STEM incorporation in the teaching of chemistry requires more than just the adoption of relevant content; rather, it involves adopting the right instructional

strategies to foster creativity and engagement. While chemistry has traditionally been taught as a theoretical subject, current pedagogical practices recognize the need to encourage active learning and foster students' ability to develop skills that are applicable across science subjects. Various strategies have proven effective in the use of STEM to teach chemistry. This paper provides an analysis and synthesis of the various strategies that can be used in such an approach.

A seminal investigation conducted by Sulaiman, Rosales Jr., and Kyung (2023), titled “Development and Evaluation of a Physics-Based STEM-PBL Module,” assessed the impact of using a PBL module on students’ motivation and academic achievements in science. Based on a quasi-experimental design approach, the researchers developed an interdisciplinary module, combining concepts from physics and chemistry by solving practical problems. This research was carried out on Malaysian secondary students. Results of the study revealed an improvement in the level of student motivation and an increase in the understanding of science-related ideas. The study found that PBL enhances both the achievement of subject content knowledge and scientific reasoning when appropriately designed.

There was also an added emphasis on the contextuality of STEM subjects. Students seemed to be more engaged and understood the lessons better when the lessons were tied up in real-life contexts, such as the reaction that takes place in our food, sustainability of the environment, or how much energy we use daily.

In the context of interdisciplinary education of science, technology, engineering, and math, there have been many cases where project-based and practical learning methods were discussed. Holbrook (2017) studied the link between STEM education and sustainable development education, emphasizing the importance of interdisciplinary teaching in bridging knowledge in sciences to issues in practice. The research sought to explore how STEM education could be changed from traditional to practical ways.

By applying an analytical approach, the writer explores ways through which learning environments can be developed to encourage the application of knowledge by

the learners in different areas of science like chemistry, biology, and environmental science. Problem solving activities in real world situations like examining an environmental problem, providing a solution to the problem, or researching the impact of human actions on the environment are typical examples of such interdisciplinary activities.

The results suggest that there is more engagement among students who learn through interdisciplinary and problem-based settings, higher critical thinking skills, and more effective application of scientific knowledge in real-life situations. Indeed, this type of approach is especially useful in teaching chemistry because there are many aspects of chemistry related to scientific and social issues.

In support of Holbrook's claim, interdisciplinary or project-based methods are vital when it comes to fostering interdisciplinarity skills among students in order for them to be prepared to tackle real-life issues that arise. Through the use of interdisciplinary or project-based learning methods, students get an opportunity to engage in problem-solving and critical thinking.

In investigating inquiry-based learning with regards to integrated STEM settings, Yang and Baldwin (2020) sought to identify how the use of technology in STEM learning could increase engagement and comprehension among learners. The purpose of their study was to investigate how the use of technology in learning could be utilized by various means, such as inquiry learning tools online, simulations, and problem-based scenarios in STEM subjects. The object of the study involved learners who were learning STEM subjects in an integrated fashion.

The results reveal that inquiry and technology-based teaching methods enable students to construct their own knowledge by interacting with real-world tasks. This implies that students taught under such conditions acquire high levels of conceptual knowledge, problem-solving skills, and motivation. It also shows that students can retain knowledge better when they actively explore it rather than being taught passively.Yang and Baldwin point out that for the most effective teaching, there should be incorporation of practical activities, collaborative work, and student inquiry in

inquiry-based STEM pedagogy. This is especially important in the field of chemistry because the abstract ideas like atomic structure and chemical reactions need visualization and hands-on experience in real-life situations. The researchers conclude that inquiry-based STEM pedagogy not only helps in improving the academic performance of students but is also crucial for developing their independent learning skills.

The other application of STEM approach to the teaching of chemistry can be observed in the study conducted by Ozhibayeva and Nurmuhanbetova (2021). In this paper, the use of STEM technologies to motivate students within the context of educational reform was assessed. The aim of the research is to find out how the integration of STEM elements such as problem-solving assignments and technology-assisted practices affect students' motivation in learning chemistry.

A classroom-based action research methodology involving secondary school learners and chemistry teachers was used for this research. The core of this research is the motivation level, engagement and the behavioral change experienced by the students during their participation in learning activities within STEM education. As part of the study process, students solved problems related to real-life situations and environmental issues through practical applications of chemistry.

The findings revealed that students who participated in activities integrating science and technology felt motivated, were more confident about themselves, and took more responsibility in the whole process of learning. This is because the assignments that required students to apply chemical principles in solving environmental problems or investigating practical aspects of chemical reactions made them take more responsibility.

Apart from the increased motivation of the students, changes in their attitudes towards chemistry were observed in a positive manner. Students showed increased interest in the course, persisted in solving difficult questions, and were willing to cooperate in teamwork. Instructors who participated in the study observed increased

initiative among students, better communication, and cooperation when working as a team.

According to Ozhibayeva and Nurmuhanbetova, the application of STEM technology to the learning of chemistry can lead not only to affective involvement on the part of learners but also to fostering high-level cognitive processes. The implementation of STEM instruction contributes to the creation of more meaningful educational setting by linking the ideas learned with their application to other subjects. Overall, the application of STEM in teaching chemistry can be considered a successful approach in view of current educational innovations.

Chiu et al. (2023) further pursued the subject matter using the lens of self-determination theory via a mixed-methods approach in their research paper titled "Community-Based STEM Learning and Its Impact on Students' Identity Development." Though the research dealt with STEM education in general terms, the focus of the interventions was on chemistry-related activities carried out in community-based projects. Student surveys and interviews at a high school were used as means of collecting data in this research. Identity formation among students and their engagement constituted the dependent variables under study. It emerges from the results that STEM activities related to chemistry helped students feel more engaged and connected with society.

Application of chemistry to projects of social significance facilitated enhancement not only of conceptual learning but also of students' feeling of identity within the sciences. According to Chiu et al., "as long as there is an identification on the part of the learner that chemistry can help solve a real problem, then the learning becomes more relevant for them, making them more likely to continue their involvement with the science." Therefore, it would be important to design the curriculum with a focus on real-life situations.

There is increasing importance being accorded to digital technologies in teaching STEM-based chemistry lessons. For example, Akçayır and Akçayır (2017) explored the application of augmented reality (AR) in an academic setting, as well as

the impacts of such applications on the process of learning by students. The primary objective was to evaluate how AR applications impact on the understanding of abstract concepts among learners.

The purpose of this paper was to evaluate the students' conceptual knowledge and the capability to create accurate mental models while engaging with learning through augmented reality. Through the systematic literature review, the authors assessed the advantages and disadvantages of using augmented reality in a classroom setting.

The conclusion drawn from these findings is that AR technology is very effective in enhancing students' spatial skills and visualization, particularly in the case of concepts that cannot be physically perceived or understood easily. The above findings can prove highly useful in the area of chemistry education as chemistry students often struggle to conceptualize molecules.

According to Akçayır and Akçayır, the use of AR technology allows students to interact with 3D images and contributes to the deep cognitive perception of information as well as helps to connect theory and practice. In particular, as far as chemistry is concerned, there are more opportunities for visualizing molecular geometry, bonds, and reaction mechanisms. Therefore, the authors claim that the implementation of AR in educational practices in the sphere of STEM may significantly increase student motivation and comprehension of complex ideas.

An alternative perspective on practice-based approaches to chemistry education can be provided by the research of Ültay and Çalık (2012). The authors investigated the influence of context-based and practice-oriented teaching methods on students' conceptual understanding of chemistry. In particular, they sought to assess the efficiency of contextualization of chemistry lessons to increase the relevance of conceptual learning and motivation for students. As part of their research, the two scholars examined the effect of including real-life examples and applications to teaching chemistry on students' learning outcomes. Thus, students from secondary schools were taught through the prism of environmental issues and practical uses of

chemicals. The key variables under analysis included students' understanding of chemistry concepts as well as their competence in applying this knowledge to practical contexts. Having completed classroom observations and tests for students, the researchers noted that those who had been involved in context-based and practice-oriented learning showed improved conceptual skills and more developed analytical thinking. Furthermore, the participants' enthusiasm for studying chemistry increased because they managed to apply learned knowledge in practical settings. Thus, Ültay and Çalık found out that practice-based education contributed to achieving higher academic results and gaining new knowledge.

Another point of view can be obtained from a systematic review by Margot and Kettler (2019), titled "Teachers' Perception of STEM Integration and Education." This review examines why certain educational approaches are chosen by teachers when integrating STEM concepts into their curriculums. While the study does not directly focus on chemistry, it states that teachers tend to utilize inquiry and project-based approaches when teaching STEM. As part of their synthesis of information taken from 40 different sources, they discovered that both real-world applications and the independence granted to students are significant factors in making decisions about methods. Additionally, it was discovered that teachers trained in cross-curricular approaches were more confident in designing lessons in which chemistry and engineering aspects were integrated. Moreover, teachers faced restrictions due to the availability of resources and institutional support when deciding how to teach STEM. In terms of chemistry education, such results suggest that both professional development and collaboration play critical roles, allowing teachers to create lessons in which concepts of chemistry could be used to solve problems in a real-world environment, thus increasing its applicability and interest to students.

As part of a larger study, Radloff & Guzey (2016) analyzed the impact of an engineering-based STEM curriculum on students' performance in science and mathematics. The quasi-experimental research design involved the implementation of an engineering-focused curriculum in which math, science, and technology were

brought together, with chemistry being introduced through material science, reaction kinetics, and energy efficiency. The major outcomes of the study included achievement and engagement. The results revealed that students performed better in both science and math courses when using the STEM curriculum, which confirms the statement that engineering design-based activities improve chemistry education through providing relevance and real-world application.

The findings above reveal the significance of engineering in improving the students' understanding of the basic concepts of chemistry. As chemistry is integrated into actual engineering processes like optimizing the conditions of reactions for energy efficiency or analyzing the characteristics of materials rather than being a standalone field of science, students would find it easier to connect theory with application. Radloff and Guzey explain that the integration of chemistry in STEM activities allows the students to think analytically and develop skills in transferring knowledge and solving problems.

In a study on the design of STEM curricula, Roehrig et al. (2021) sought to investigate how STEM integrated curricular units were implemented in class. The purpose of this study was to understand the nature of an effective STEM curriculum and the key components that help in integrating different disciplines. The study utilizes a qualitative analysis method, and the focus of the study is on the incorporation of inquiry and engineering design in STEM instruction.

Various STEM curriculum modules designed and delivered by classroom teachers have been analyzed in this investigation with particular emphasis on interdisciplinary connections within the curricula. Based on the findings, there is no doubt that any good STEM teaching entails inquiry and group work as well as problem-solving activities that push the learner to connect knowledge from different disciplines. In chemistry education, such methods enable learners to connect theoretical knowledge of chemistry to its application.

Conclusively, according to Roehrig et al., successful teaching of STEM subjects requires pedagogical frameworks that ensure integration of disciplines without losing

clarity regarding learning objectives. In other words, they argue that coherence of instructions, scaffolding, and consistency in relation to learning objectives are among the vital determinants to ensure engagement with difficult concepts.

The above studies illustrate the wide variety of instruction strategies that have been effectively utilized in the context of integrated STEM chemistry teaching. This transition ranges from approaches based on projects and inquiry to those involving technology and reality into the classroom. Indeed, the studies provide a clear illustration of how content delivery methods in education are being transformed from the former, passive type into the more proactive student-oriented mode of inquiry learning.

Moreover, the research suggests that any successful STEM-based chemistry teaching should involve a fundamental change in the approach to education. In other words, rather than focusing entirely on knowledge transfer, teachers are expected to create environments that will emphasize exploration, collaboration, and connections between subjects. The rationale behind this recommendation is rooted in modern pedagogical trends geared toward solving real-life problems.

In an analysis of studies from theory as well as practice, some important aspects can be noted. The first aspect includes the understanding that STEM education as a global learning system is inherently dependent upon the application of interdisciplinary knowledge and problem-solving abilities in addition to student involvement. The significance of these aspects in the field of chemistry, which involves the use of many theories that require visualization and implementation, is highly pronounced. The second aspect involves the challenges associated with interdisciplinary chemistry education despite its importance being acknowledged.

Thirdly, there are different teaching techniques such as project-based learning, inquiry-based methods, engineering-design problems, and use of technology that have been proven effective for teaching chemistry with the use of STEM approaches. This becomes more powerful especially when these teaching techniques are anchored on real-life situations.

In summary, these results point to the need for instructional frameworks that are well structured and flexible enough to facilitate the integration of science and mathematics in teaching chemistry. Moreover, they demonstrate the importance of teacher training and institutional support for effective realization of these approaches. The current study builds on these recommendations by investigating the application of such instructional frameworks in chemistry education and identifying the most efficient methods described in modern scientific literature.

In proceeding to the next chapter of this study, the methodology chapter will outline how the findings from the theory and previous empirical literature have helped in designing the research methodology that has been applied to study the implementation of STEM in teaching chemistry.

METHODOLOGY

Methodology is considered as an integral part of the study as it details the methods by which data will be gathered, analyzed, and interpreted. It specifies the measures that can ensure the validity and reliability of the results. The study aims to evaluate the effectiveness of the teaching strategies used in integrated STEM-based teaching and analyze their use in chemistry teaching. The research focuses on establishing the teaching strategies used in STEM-integration through an extensive review of related literature, and determining their impact on the academic achievement and experiences of students. The current research seeks to explore both theoretical and practical aspects of STEM-integrated teaching in order to develop a better understanding of the importance of this approach in modern-day chemistry teaching.

2.1 Research Design

This research employs an approach that is known as mixed method research design. This approach involves both qualitative and quantitative research methods. It allows the researchers to develop a complete understanding of the integration of STEM into the teaching of chemistry.

In the first phase, a qualitative approach was applied through the analysis of scientific literature. The purpose of this phase was to identify commonly used instructional methods and learning activities in STEM-integrated chemistry education, as well as to determine current research trends. Based on the analysis of selected studies, the most frequently used instructional methods were identified and selected for further implementation.

During the second phase, a quantitative research approach was used by adopting the quasi-experimental design using the pretest and posttest control group model. Experimental groups were taught using STEM integrated approach obtained in the first phase while the control group used the conventional method of teaching. With this approach, it was possible to make comparisons between the performances of the two groups of students.

Additionally, a survey for reflective feedback was administered to the students of the experimental groups to assess their perceptions, involvement in the process, and challenges faced while teaching the STEM-informed courses. The findings were then analyzed based on the information gathered from the survey.

All in all, the research design demonstrates that there is a clear connection established between the theoretical review and the application in classrooms.

2.2 Sampling

The research utilized both qualitative and quantitative samples that corresponded to the methodology of the research. Specifically, 30 scholarly papers that had been associated with the concept of integrated STEM education in the context of chemistry were selected as a sample. This sample was gathered using the database of Google Scholar by employing such keywords as integrated STEM, STEM in chemistry, and the integration of STEM disciplines. The studies under consideration have been published within the period ranging from 2020 to 2025.

Selection criteria for the articles included the relevance to the research subject, especially the aspect of teaching methodologies and integration of STEM into the chemistry classes. These qualitative samples would form the basis from which to establish the most common STEM-integrated teaching methodologies that would later be used during the experiment phase of the research. During the quantitative phase, the samples were selected using convenience sampling.

The total sample was represented by 123 ninth grade students within the age range of 14 to 15 years old who were selected from schools in Almaty, the Republic of Kazakhstan, for the academic period 2025-2026. Students were selected from three different types of schools which were the International School, Lyceum, and General Secondary School. Two classes were taken from each school.

The number of students in each school was as follows:

- International School: 17 and 19 students;
- Lyceum: 18 and 19 students;
- General secondary school: 24 and 26 students.

The current classes served both as experimental classes and control classes, where participants were not randomly assigned to either of the two groups. Where applicable, classes that had the same previous performance in chemistry were selected to ensure equivalence between groups. The experimental group used STEM integrated instructions for teaching, while the control group used the conventional method of teaching. Sixty-three participants from the experimental group also undertook a reflective feedback survey.

2.3 Data collection

2.3.1 Qualitative data collection

Data were collected using qualitative and quantitative methods. Qualitative data came from literature analysis and students' perceptions, while quantitative data were obtained from pre- and post-test results. This approach provided a comprehensive understanding of the outcomes and supported triangulation, increasing the validity and reliability of the results.

As regards the qualitative part of the study, 30 articles related to the integration of STEM into chemistry education were selected for analysis. These articles were identified through searches in Google Scholar using the keywords "integrated STEM," "STEM in Chemistry," and "integration of STEM disciplines." All selected studies were published between 2020 and 2025. This time frame was chosen to ensure the inclusion of recent and relevant research on STEM integration in chemistry education. The selected articles were analyzed to identify common STEM instructional approaches and examine their impact on students' academic achievement, engagement, and motivation. Detailed information regarding the selected studies, including authors, article titles, research aims, and the implementation of STEM instructional methods and activities, is provided in Appendix 1 (pp. 80–93).

2.3.2 Quantitative Data Collection

The quantitative data were collected through a pedagogical experiment using a pre-test and post-test control group design.

In each participating school, both experimental and control groups completed a pre-test in the form of a summative assessment for the previously studied unit, which was provided as part of the school curriculum. The results of this assessment were used as baseline data to determine students' prior knowledge and to ensure comparability between the groups.

Following the pre-test, the instructional intervention was conducted over three lessons based on a new chemistry unit. In the experimental groups, the lessons were organized using STEM-integrated instructional methods, while in the control groups the same topics were taught using traditional textbook-based approaches.

After the completion of the instructional period, both groups completed a post-test, which was also conducted in the form of a summative assessment for the newly studied unit. The results of the post-test were used to measure students' learning outcomes and to evaluate the effectiveness of STEM-integrated instruction compared to traditional teaching methods.

The experiment was implemented across three schools using different chemistry units:

- General secondary school – Chemical elements in the human body;
- Lyceum – The rate of chemical reactions;
- International School – Group 16 and 17 elements and their compounds.

The same assessment structure and conditions were applied in both experimental and control groups in each school to ensure consistency and reliability of the results.

- **General secondary school**

The educational experiment carried out at the general secondary school was carried out for three weeks. Formal permission had been obtained from the management of the institution before conducting the study, and the procedures followed adhered to ethical considerations. The students and their guardians had been briefed on the purpose of the research.

A total of 50 ninth-grade students participated in the study, including 26 students in the experimental group and 24 students in the control group. Two intact classes were

selected, with one assigned as the experimental group and the other as the control group. Before the intervention, both groups completed a pre-test in the form of a summative assessment based on the previously studied unit “Group 17, 16, and 15 Elements and Their Compounds.” The pre-test consisted of six questions (see Appendix 2, pp. 94–96) and was administered to evaluate students’ prior knowledge. Since the assessment tasks were officially approved and provided by the school administration. Since the pre-test and post-test instruments were adapted from officially approved Summative Assessment for the Unit (SAU) materials available on the SchoolHack.kz educational platform and were implemented with the approval of the school administration, additional validity analysis was not deemed necessary. These assessment tasks had already undergone expert review and were aligned with the national curriculum requirements. Therefore, the present study focused on examining the reliability of the assessment instrument using Cronbach's Alpha coefficient.

The reliability statistics of the assessment instrument used for the pre-test and post-test in the general secondary school are presented in Table 2.3.2.1. The instrument consisted of two components: the pre-test and the post-test. Cronbach’s Alpha value was 0.955 for 50 students, indicating a very high level of internal consistency. This result confirms that the assessment instrument was reliable for measuring students’ learning outcomes before and after the instructional intervention. Reliability analysis was conducted using IBM SPSS Statistics software.

Table 2.3.2.1. Reliability Statistics of the Pre-test and Post-test (General secondary school)

Reliability Statistics (General secondary school)	
Cronbach's Alpha	N of Items
.955	2

The instructional intervention consisted of three lessons based on the unit “Chemical Elements in the Human Body”. In the experimental group, instruction was conducted using STEM-integrated methods, with particular emphasis on problem-

solving tasks, collaborative learning, interdisciplinary tasks, and student-centered learning activities, while the control group was taught using traditional teaching approaches.

The first lesson began with a visual activity in which students observed images of chemical elements, human organs, and food sources, and were asked to identify the topic of the lesson. This was followed by theoretical instruction on the chemical composition of the human body, including macro- and microelements. Students were engaged through problem-based questions related to the role of elements in the human body and the effects of their deficiency. They were then divided into groups and assigned specific elements (Mg, Ca, K, Fe) to prepare a mini-project on their biological role, deficiency symptoms, and sources in food. This stage of the lesson was organized as a form of collaborative learning, where students worked together, shared ideas, and developed their understanding through group interaction.

As one aspect of the technology part of the STEM learning model, students used computer tools and educational resources available on the Internet to obtain information about the chemicals and to make presentations regarding the same. In addition to that, they used computers for making calculations and creating spreadsheets.

Lesson two began with a presentation followed by discussions where the learners gave reports on their group assignments. In addition, the class dealt with heavy metals and their effects on protein denaturation through discussion.

In connection to the engineering aspect of the STEM concept, students were made to undertake a design project involving both human health issues and chemical elements. They were assigned the design of a basic water filter that would effectively decrease the presence of heavy metals in drinking water. Using common materials like sand, cotton, charcoal, plastic containers, and filter papers, students designed and built their models for water filters. After analyzing the efficacy of the designs through experiments, they identified which materials produced the most effective results and discussed how the knowledge of chemistry can solve real-life problems. Through the

said activity, students were able to develop their engineering thought processes, problem solving skills, creativity, and ability to apply chemistry concepts in practical situations.

Next, there was a student-based activity, where students were analyzing information that is given in Appendix 4 (p. 109, Calculation of the cost and mass fraction of chemical elements in the human body). In the process of the activity, students estimated the value of various elements found in the human body, thus fostering independence of mind, decision making, and practical use of information. The assignment itself was interdisciplinary since it involved not only knowledge about chemistry but also included math as well as practical knowledge associated with economic life. The topic of the lesson also involved the study of heavy metals and their role in protein denaturation.

In relation to the concept of STEM education, the students were given a task of solving a real world problem as homework, whereby they were supposed to come up with some strategies that could help reduce the effect of these heavy metals on human beings. This was done in the third class session where the students would present their suggested solutions. A test and several case problems would then be administered to the students.

After the teaching experiment, both the experimental and control groups took a post-test, which served as a summative evaluation for the unit under study. The post-test scores were used to measure the level of learning achieved by the students and to evaluate the effectiveness of the STEM-based teaching methods used in class. The post-test questions are provided in Appendix 2 (pp. 96–98).

Sample STEM-based lesson activities implemented during the intervention at the General Secondary School are provided in Appendix 4 (p. 109).

- **Lyceum**

The educational experiment that was performed in the lyceum lasted for three weeks. Before starting the experiment, necessary permission was granted by the school authorities, and the experiment was performed in accordance with ethical

considerations. The objectives of the experiment were explained to students and their parents.

The research involved 37 ninth graders, among which 18 served as members of the experimental group while 19 made up the control group. Two whole classes were selected; one served as the experimental group while the other constituted the control group.

Before the implementation of the intervention, the two groups were tested based on the pre-existing unit, which is the “Qualitative Analysis of Inorganic Compounds.” This is to determine their prior knowledge and guarantee similarity among them. There were six questions included in the assessment test (refer to Appendix 2, pp. 98-101).

The pre-test and post-test instruments used in the Lyceum were adapted from summative assessment tasks available on the BilimLand educational platform. These assessment materials are developed in accordance with the national curriculum requirements and are widely used in educational practice. Since the assessment tasks had been approved by the school administration for instructional purposes, additional validity analysis was not considered necessary for this study. Therefore, the reliability of the assessment instrument was examined using Cronbach's Alpha coefficient, while data analysis was conducted using IBM SPSS Statistics software.

Table 2.3.2.2. Reliability Statistics of the Pre-test and Post-test (Lyceum)

Reliability Statistics (Lyceum)	
Cronbach's Alpha	N of Items
.921	2

According to Table 2.3.2.2, Cronbach’s Alpha value was 0.921 for 37 students, indicating a very high level of internal consistency. This result confirms that the assessment instrument, which included both the pre-test and post-test, was reliable for measuring students’ learning outcomes before and after the instructional intervention.

Instruction was done through three lessons taken from the unit titled, "Rate of Chemical Reactions." In the experimental group, the methods applied for teaching involved STEM integration, especially focusing on problem solving, collaboration,

multidisciplinary approach, and learner-centeredness. However, in the control group, the lesson was delivered using conventional textbook-based approaches.

As the first lesson, the concept of reaction rates was discussed using practical scenarios for quick and slow reactions. The students were led to ask themselves the question, “How does one measure the rate of a reaction?”, which was then explained using proper formulae. The next question asked was, “Why are some reactions quick while others take time?” and this question opened up a discussion on what causes reaction rates to vary depending on various factors such as concentration, pressure, surface area, temperature, catalysts, and in some cases, light (photosynthesis). It is at this point that the Technology aspect of the STEM curriculum came into play, as students were taken through simulations using a virtual lab created using java. With the use of simulations, students were able to visualize how reactions vary depending on the factors like concentration, temperature, and pressure affecting reaction rates.

The second lesson focused on laboratory and collaborative activities. Students were divided into groups and conducted experiments investigating factors affecting reaction rates, including:

1) Iodine Clock Reaction (effect of concentration);
2) Dissolution of sugar cube vs. powdered sugar (effect of surface area);
3) Hydrogen peroxide decomposition with MnO_2 (effect of catalyst).

After the experimentation process, students engaged in data analysis, conclusion drawing, and report writing within a collaborative learning context.

The next step in the experiment saw the experimental class working on an engineering application that was based on the paper “Anti-Browning and Oxidative Enzyme Activity of Rice Bran Extract Treatment on Freshly Cut Apple” (Lee et al., 2022). This particular exercise involved problem solving, in which the students analyzed a realistic issue involving enzymatic browning and then came up with a feasible solution to it. Based on scientific knowledge presented in simplified terms, the learners looked at what affected browning of the apples and used that information to design a solution for it.

This task emphasized problem-solving skills, critical thinking, and decision-making, as students evaluated the effectiveness of their solutions and refined their ideas based on observation, while also incorporating elements of the engineering design process.

The third lesson included presentation and discussion, where students presented their project results and participated in a short quiz. In addition, students were given individual problem tasks related to chemical reactions, where they analyzed the effect of different factors on reaction rates. This stage emphasized independent reasoning and student-centered learning.

After the completion of the instructional period, both the experimental and control groups completed a post-test administered as a summative assessment for the studied unit. The obtained results were used to assess students' learning outcomes and determine the effectiveness of STEM-integrated instruction. The pre-test and post-test questions are provided in Appendix 2 (pp. 101–103).

Sample STEM-based lesson activities implemented during the intervention at the Lyceum are provided in Appendix 4 (pp. 109-110).

- **International School**

The educational experiment at the International School took place within three weeks. Prior to conducting the experiment, the approval of the school management was obtained, and all activities adhered to ethical principles. The purpose of the research was explained to both participants and their parents, and no one was forced to participate.

A total number of 37 students in ninth grade was involved in the research: 19 for the experimental group and 18 for the control group. Two intact classes were used for the experiment; one class formed the experimental group, while the other class was used as the control group. Before carrying out the experiment, both groups took a pre-test which was in the form of a summative test after the previously discussed topic "Group 15 Elements and Their Compounds". The pre-test was conducted to determine

students' background knowledge. There were six items in the assessment tool (Appendix 2, pp. 103-104).

The pre-test and post-test instruments used in the International School were adapted from official Cambridge IGCSE Chemistry assessment materials developed by Cambridge Assessment International Education and supplementary summative assessment tasks available on the BilimLand educational platform. The Cambridge IGCSE materials follow internationally recognized curriculum and assessment standards, while the BilimLand tasks are aligned with national educational requirements. Since these assessment materials had already been developed for educational assessment purposes and their use was approved by the school administration, additional validity analysis was not considered necessary for this study. The reliability of the assessment instrument was examined using Cronbach's Alpha coefficient, while data analysis was conducted using IBM SPSS Statistics software.

Table 2.3.2.3. Reliability Statistics of the Pre-test and Post-test (International School)

Reliability Statistics (International School)	
Cronbach's Alpha	N of Items
.919	2

As shown in Table 2.3.2.3, Cronbach's Alpha coefficient was 0.919 for 37 students, indicating a very high level of internal consistency. This result confirms that the assessment instrument, which included both the pre-test and post-test, was reliable for measuring students' learning outcomes before and after the instructional intervention.

The instructional intervention consisted of three lessons based on the unit "Group 16 and 17 Elements and Their Compounds". In the experimental group, instruction was conducted using STEM-integrated methods, with particular emphasis on problem-solving tasks, collaborative learning, interdisciplinary tasks, and student-centered learning activities.

The first lesson focused on Group 16 elements, particularly sulfur. Students were introduced to the general properties, occurrence in nature, allotropy, and chemical

behavior of sulfur and its compounds. The use of the interdisciplinary approach could be seen in the lesson when chemistry ideas were related to industrial and environmental issues involving sulfur. As for the Technology portion of STEM education, it can be seen in how multimedia was used to illustrate chemical transformations of sulfur molecules.

The problem-based laboratory lesson involved the use of the following key question, which was the foundation of the experiment, “Why does sulfur have varying physical properties when its molecules are uniform (S)?” The process entailed heating of the element to the melting point followed by rapid cooling of the same, hence forming plastic sulfur. The students analyzed the formation of linear polymers from S8 cyclic molecules.

Meanwhile, the Engineering aspect of STEM integration was achieved via components of Materials Engineering. Through the synthesis of plastic sulfur, students learned about how heating could affect the structure and properties of a substance. In this context, they studied the effect of heat on the conversion of crystalline S_8 cyclic molecules into polymeric sulfur chains, considering the application of the principle in materials engineering and industries. The real-life applications of the concept that were considered included rubber production, vulcanization, fertilizer and chemical industries. Such an exercise encouraged critical thinking, problem solving, and inquiry driven learning as the students learned to interpret the outcomes and develop their own understanding.

The second lesson involved the Group 17 elements, otherwise known as halogens. Their general characteristics, electronic structure, and periodic trends were taught in this level. Interdisciplinary connections between chemistry, biology, and environmental science were made at this stage through the examination of the practical application of halogens to living things and water purification.

The aspect of Technology was dealt with by discussing the process of the production of chlorine in the lab setting as well as in industries. During the production of chlorine in the lab activity, the lab procedures used to produce chlorine were viewed

by students, and then safety issues related to working with reactive gases were discussed. Students also looked at the technologies that are used to produce chlorine commercially and studied uses of chlorine in water purification, sanitation, disinfectants, and chemical industries.

After completing the demo, the students carried out some problem solving activities that involved writing and checking chemical equations and doing calculations on their own. Collaboration was emphasized in terms of discussion and testing. On the other hand, learner-centeredness was promoted by making learners observe, conclude, and explain their work independently.

On the other hand, the Engineering dimension was incorporated into lessons involving the application of halogen chemistry in industry and in addressing environmental issues such as water purification processes, disinfection processes, bleaching processes, and various materials processing. It enabled students to learn how chemical science is applied in engineering practices.

Thirdly, there was a lab exercise which involved group work whereby students were required to participate in laboratory activities that would be based on chemical reactions involving elements from Groups 16 and 17. In these group discussions, students were engaged in laboratory experiments involving reactions between hydrochloric acid, zinc, and sodium hydroxide while at the same time writing molecular equations. This activity enabled them to develop further critical thinking skills.

Problem solving and inquiry-based learning were emphasized through this experiment since the students were required to analyze the outcomes, explain changes in structure, and construct knowledge independently. Concepts of structure-property relations in chemistry were also enhanced through this exercise.

After the instructional session, the two groups took part in a post-test conducted as a summative assessment for the unit under study. The test results were analyzed to evaluate students' academic achievement and determine the effectiveness of STEM-

integrated instruction. The post-test questions are provided in Appendix 2 (pp. 105–107).

Sample STEM-based lesson activities implemented during the intervention period are provided in Appendix 4 (p. 110).

2.3.3 Reflective Feedback Survey Data Collection

A reflective feedback survey was also conducted to gain deeper insight into students' perceptions and experiences related to STEM-integrated instruction, complementing the quantitative data collected through pre- and post-tests. The survey provided valuable information regarding students' engagement, attitudes, and learning experiences during the implementation of STEM-based lessons. These data helped to explain how students perceived the effectiveness of STEM-integrated instruction and supported a more comprehensive interpretation of the research findings.

Before conducting the survey, the survey instrument, which consists of four questions, was subjected to expert judgment from four experts in STEM education and science teaching to ascertain its content validity. The four experts evaluated the appropriateness, relevance, and suitability of each question based on the study's objectives. The detailed mean scores assigned by the experts for each evaluation criterion are presented in Appendix 3 (p. 108). Expert judgments were analyzed using Kendall's W (coefficient of concordance) using SPSS Statistics software. Mean ranks given by the experts for each criterion of evaluation are shown in Table 2.3.3.1.

The mean rank values show that the experts evaluated the survey items in a generally consistent and balanced manner across the selected criteria, indicating a similar understanding of the relevance and clarity of the survey questions.

Table 2.3.3.1. Mean Ranks Assigned by Experts for Survey Validation Criteria

-	Mean Rank
Q.1	3,13
Q.2	1,13
Q.3	2,63
Q.4	3,13

To determine the level of agreement among the experts regarding the evaluation criteria, Kendall's coefficient of concordance (W) was calculated. This statistical measure was used to assess the consistency of expert judgments and the degree of consensus among the evaluators. The results of the analysis are presented in Table 2.3.3.2.

Table 2.3.3.2. Results of Kendall's Coefficient of Concordance Analysis

N	4
Kendall's W[a]	,827
Chi-Square	9,923
df	3
Asymp. Sig.	,019
a. Kendall's Coefficient of Concordance	

The analysis indicated a high level of agreement among the experts (W = .827), which was statistically significant, $\chi^2(3) = 9.923$, $p = .019$. These findings confirmed that the survey instrument was valid and appropriate for data collection.

After the implementation of the intervention, the survey was conducted online using Google Forms. The survey was limited to participants from the experimental groups, as they were the students who took part in the intervention program. Overall, 63 ninth-grade students from three schools participated in the survey.

To ensure clarity and easy understanding, two versions of the survey were developed. In general secondary schools where the language of instruction is Kazakh, students completed the Kazakh version of the survey. In the lyceum and international school, the English version was used, as English was the language of instruction there. This helped ensure that all respondents fully understood the survey items. The survey questions are provided in Appendix 3 (p. 108).

The survey mainly consisted of structured items designed to quantitatively measure students' perceptions of their experience with integrated STEM instruction. The survey covered different aspects of the learning process, including students' understanding of STEM-based lessons, classroom involvement, interest in chemistry, preferred mode of learning, and difficulties faced during the lessons.

The data were analyzed using descriptive statistics. Students' survey responses were examined through frequencies and percentages to identify their perceptions and experiences related to STEM-integrated teaching methods. This analysis also helped reveal trends in students' engagement, motivation, collaboration, and attitudes toward STEM-based learning. The survey findings provided answers to the third research question.

2.4 Data Analysis

The following section will describe the process followed in analyzing the collected data with the objective of finding answers to the research questions posed and examining the efficiency of STEM integration in teaching chemistry. This analysis was done with respect to the research design and entailed qualitative and quantitative methods.

In order to conduct an analysis of qualitative data, content analysis was done. As many as 30 papers were reviewed in detail in order to determine common teaching methods used in integrated STEM chemistry. In the process of review of these papers, similar trends were detected and then placed under different categories. Each method was evaluated according to its frequency in order to establish what the most common ones were. This helped choose the teaching methods that would be employed during experiments.

In conducting the analysis of the quantitative data, Analysis of Covariance (ANCOVA) was used. The calculations were conducted in Jamovi version 2.7.12. In this technique, the post-test results were taken as the dependent variable while the group assignment was used as the independent variable. The pre-test result was used as the covariate in order to make up for any differences in prior knowledge.

Before the implementation of the ANCOVA, assumption tests were done to establish the validity of the statistical process used. Tests on normality of the data were done using the Shapiro-Wilk Test, while tests for homogeneity of variance across groups were done using Levene's Test. In addition to these, Q-Q plots were constructed to check whether there is normality of the residuals. All the assumptions were tested

for each of the schools that participated in the study. The results are shown in Appendix 5 (pp. 111–112) .

Moreover, descriptive statistics analysis was done on data collected from the reflective feedback questionnaire. The questionnaire was done only among the students in the experimental group, who were under STEM integration lessons. There were 63 respondents for this part of the study. Data analysis was done based on frequency counts and percentages to establish general trends related to their perceptions, interest, learning preferences, and difficulties in the integration of STEM lessons.

RESULTS

This chapter will contain the research findings regarding the research questions. There will be three parts to the presentation of the results. Firstly, there will be a report on the qualitative analysis findings with an emphasis on the determination of popular methods used for integrating STEM as well as trends in chemistry education research. Secondly, there will be reporting of the quantitative analysis findings which will evaluate the effect of these methods on the performance of learners by comparison of experiment and control groups.

3.1 Results of Qualitative Analysis (RQ1)

This section addresses Research Question 1: What STEM integration methods are used in chemistry instruction, and what trends can be identified in chemistry education research? To answer this question, a qualitative content analysis of 30 peer-reviewed articles published between 2020 and 2025 was conducted. The analysis identified thirteen STEM instructional methods and activities, revealing that interdisciplinary approaches, problem-solving tasks, and collaborative learning are the most consistently represented across the reviewed literature, while digital technologies and modeling remain less prevalent.

The analysis of 30 carefully chosen academic papers was performed to reveal the main approaches to STEM integration in teaching chemistry that are used most often and determine the dominant trends in the field of chemistry education research. This analysis was focused on teaching techniques and activities and interdisciplinary approaches discussed in literature from 2020 to 2025. Special attention was paid to those approaches which promote active learning, critical thinking, teamwork, and the use of scientific knowledge.

From the analysis above, it can be noted that there is a variety of instructional techniques used in teaching chemistry that incorporates STEM concepts. In total, there are thirteen instructional techniques used. There are numerous studies that have emphasized the importance of incorporating concepts of technology, engineering, and mathematics into the teachings of chemistry in order to facilitate better comprehension

of students. The general distribution of these techniques is shown in Figure 3.1.1 below, where various instructional techniques frequently used in current studies are shown and analyzed.

Figure 3.1.1. Effective STEM instructional methods and activities identified through literature analysis



A detailed explanation of each identified instructional method that was used in this study can be found in Table 3.1.1, which presents a list of operational definitions that were used in the whole dissertation. It explains what each of the instructional methods means, how it should be used, and what purpose it serves within the framework of STEM-based chemistry instruction. In addition, the table specifies how each of the instructional methods helps learners become more engaged in the learning process, solve problems, collaborate, and learn across disciplines. All these operational definitions helped develop a thorough understanding of each of the chosen instructional methods and organize the instructional intervention in an efficient way.

Table 3.1.1. Identified STEM instructional methods and activities with definitions (as used in this dissertation)

№	Instructional method and activities	Definition (used in this dissertation)
1	Hands-on laboratory activities (including laboratory experiments)	Practical activities in which students conduct experiments, manipulate materials, and observe scientific or chemical phenomena.
2	Problem-solving tasks	Activities in which students analyze problems and develop solutions.
3	Inquiry activities	Activities involving question formulation, data collection, and evidence-based conclusions.
4	Engineering design tasks	Iterative processes of designing, testing, evaluating, and improving solutions to STEM-related problems
5	Project work / mini-projects	Extended tasks in which students create a product or solution by integrating STEM knowledge.
6	Modeling (physical and digital models)	The use of physical or digital representations to explain, visualize, or predict scientific and chemical processes.
7	Use of digital technologies (simulations, virtual labs, AR/VR)	The use of digital tools, including simulations and virtual laboratories, to support understanding of scientific phenomena.
8	Collaborative learning	Structured group work in which students jointly solve problems, share responsibilities, and make decisions.
9	Interdisciplinary approach	Learning activities integrating concepts and skills from multiple STEM disciplines.
10	Data collection and analysis	Activities involving the collection and analysis of data to support scientific reasoning.
11	Student-centered learning activities	Instructional activities that emphasize student autonomy, active participation, and responsibility for learning.
12	Presentation and communication activities	Activities in which students present and communicate scientific ideas or findings.
13	Reflection and discussion	Activities that encourage students to reflect on their learning process and discuss results, challenges, and conclusions.

In order to provide a more thorough description of the analyzed studies, the distribution of STEM teaching methods and activities was examined. This analysis enabled a systematic comparison of the frequency of various teaching techniques and identified the methods most commonly used in STEM-based chemistry instruction. It also determined which techniques were associated with active learning, interdisciplinary integration, collaboration, inquiry-based teaching, and real-life problem-solving. Particular attention was given to the use of digital technologies, laboratory activities, projects, and statistical analysis, as these aspects have been widely discussed in previous studies.

The study of the distribution of teaching methods gave an opportunity not only to describe the current pedagogical trends in STEM teaching but also to understand their application in actual teaching and learning processes. The distribution table is shown in Appendix 6 (pp. 113–115).

Based on Appendix 6 (pp. 113–115), the frequencies and percentages of instructional strategies used in the reviewed articles were calculated. The results are summarized in Table 3.1.2, which provides a quantitative overview of the most common STEM-related strategies in the analyzed literature. It also shows the main instructional focuses and dominant approaches in modern integrated science instruction.

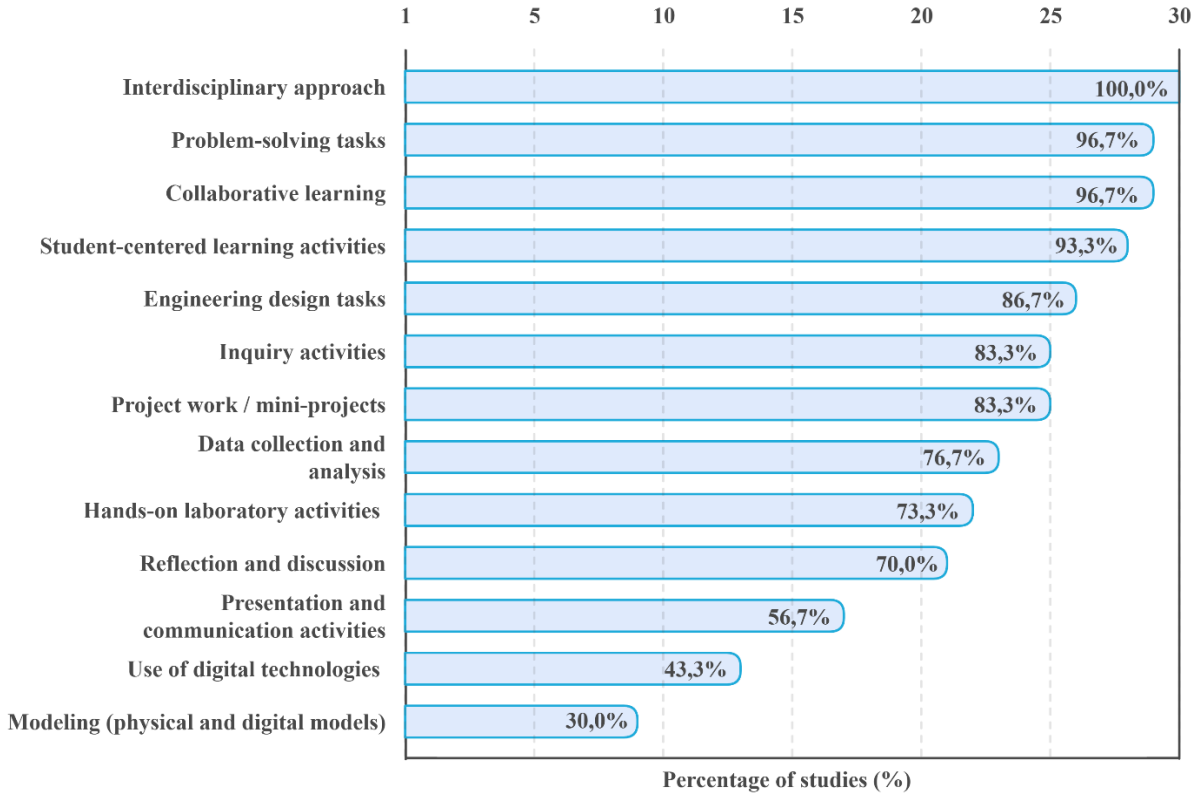
Moreover, the findings highlighted the growing importance of learner-centered approaches involving practical tasks, cooperation, discussion, and interdisciplinary problem-solving. Finally, the data provided a basis for selecting instructional strategies for the experimental part of this research.

Table 3.1.2. Frequency and percentage of STEM instructional methods and activities in the analyzed studies

№	Instructional Method	Frequency	Percentage
1	Hands-on laboratory activities (including laboratory experiments)	22	73,3%
2	Problem-solving tasks	29	96,7%
3	Inquiry activities	25	83,3%
4	Engineering design tasks	26	86,7%
5	Project work / mini-projects	25	83,3%
6	Modeling (physical and digital models)	9	30%
7	Use of digital technologies (simulations, virtual labs, AR/VR)	13	43,3%
8	Collaborative learning	29	96,7%
9	Interdisciplinary approach	30	100,0%
10	Data collection and analysis	23	76,7%
11	Student-centered learning activities	28	93,3%
12	Presentation and communication activities	17	56,7%
13	Reflection and discussion	21	70%

To facilitate better interpretation of these results, the percentage distribution of the identified instructional methods is illustrated in Figure 3.1.2. The figure provides a visual representation of the frequency of each instructional approach identified in the analyzed studies and allows for easier comparison between the methods. It also highlights the instructional strategies that were most commonly applied in STEM-integrated chemistry education research between 2020 and 2025.

Figure 3.1.2. Percentage distribution of STEM instructional methods and activities in the analyzed studies



To facilitate interpretation, the percentage distribution of the identified instructional methods is illustrated in Figure 3.1.2. The figure shows that the interdisciplinary approach (100%) is present in all studies, while problem-solving tasks and collaborative learning (96.7%) are also widely used. In addition, student-centered learning activities (93.3%), engineering design tasks (86.7%), and inquiry-based and project-based activities (83.3%) are frequently implemented.

At the same time, data collection and analysis (76.7%) and hands-on laboratory activities (73.3%) are less consistently represented, and the lowest frequencies are observed for the use of digital technologies (43.3%) and modeling (30.0%).

Overall, the results show that STEM-integrated chemistry instruction is predominantly characterized by interdisciplinary, problem-based, collaborative, and student-centered approaches, while technological and modeling components appear less frequently in the analyzed studies.

3.2 Results of Quantitative Analysis (RQ2)

This section addresses Research Question 2: What impact do commonly used STEM integration methods have on students' learning outcomes and engagement? To answer this question, a quasi-experimental design was implemented across three schools in Almaty, Kazakhstan, involving 123 ninth-grade students divided into experimental and control groups. Pre-test and post-test scores were compared using ANCOVA, with pre-test results controlled as a covariate. Across all three educational settings, the experimental groups demonstrated statistically significantly higher post-test scores than the control groups, indicating a positive effect of STEM-integrated instruction on students' academic performance.

Quantitative data gathered from the educational experiment were analyzed to determine the possible effects of STEM-based teaching approaches on students' learning process and academic performance. The effectiveness of the intervention was assessed by comparing the post-test scores of students in the experimental and control groups after the experiment.

The analysis was conducted using ANCOVA, where the dependent variable was the students' post-test scores, and the independent variable was the group type, namely experimental or control. Pre-test scores were included as a covariate to control for possible differences in students' initial knowledge before the intervention. The results are presented separately for each school, beginning with descriptive statistics of the pre-test scores, followed by the ANCOVA results and post-hoc test findings.

3.2.1 Results from the General Secondary School

Before conducting the ANCOVA test, it was necessary to consider the descriptive statistics of the pre-test scores to get a clear idea about how the group performed before the experiment. In addition, this can be used to evaluate the level of knowledge that the students had before implementing the intervention. The mean have been considered in this regard.

Descriptive results showed that the pretest mean score of the control group was slightly higher than that of the experimental group, suggesting a minor variation in the prior knowledge level of students before the treatment period. The descriptive statistics for the pre-test and post-test scores of both the experimental and control groups types are presented in Appendix 7 (p. 116).

The results of the ANCOVA analysis for the general secondary school are presented in Table 3.2.1.1 and Table 3.2.1.2.

As seen from Table 3.2.1.1, the influence of the group variable had been found to be statistically significant for post-test scores ($F = 29.8$, $p < .001$). This is an indication that there existed a difference between the two groups based on their pre-test scores. Moreover, pre-test scores were also found to be statistically significant ($F = 417.3$, $p < .001$).

Table 3.2.1.1. ANCOVA Results for Post-Test Scores – General Secondary School

ANCOVA - post test

	Sum of Squares	df	Mean Square	F	p
pre test	580.7	1	580.69	417.3	<.001
Group	41.5	1	41.51	29.8	<.001
Residuals	65.4	47	1.39		

The post hoc comparison results are presented in Table 3.2.1.2. The findings show that the experimental group achieved higher results than the control group, with a mean difference of 1.83 ($p < .001$). This statistically significant difference indicates that students who received STEM-integrated instruction performed better in the post-

test. Therefore, the result demonstrates the positive effect of STEM-based teaching on students' learning outcomes and supports the effectiveness of the instructional intervention.

Table 3.2.1.2. Post Hoc Comparison of Experimental and Control Groups – General Secondary School

Post Hoc Comparisons - Group

Comparison							
Group		Group	Mean Difference	SE	df	t	p_{tukey}
Experimental	-	Control	1.83	0.336	47.0	5.46	<.001

This result demonstrates a positive effect of STEM-integrated instruction on students' learning outcomes.

3.2.2 Results from the Lyceum

Before conducting the ANCOVA analysis, descriptive statistics for the pre-test scores were examined to provide an overview of the initial performance of the experimental and control groups. The descriptive statistics for the pre-test and post-test scores of both the experimental and control groups for the Lyceum sample are presented in Appendix 7 (p. 116).

The descriptive results indicated that the experimental group demonstrated a slightly higher mean pre-test score than the control group, suggesting a difference in students' prior knowledge before the intervention.

The results of the ANCOVA analysis for the lyceum are presented in Table 3.2.2.1 and Table 3.2.2.2.

Table 3.2.2.1. ANCOVA Results for Post-Test Scores – Lyceum

ANCOVA - post test

	Sum of Squares	df	Mean Square	F	p
pre test	206.3	1	206.33	180.3	<.001
Group	28.9	1	28.93	25.3	<.001
Residuals	38.9	34	1.14		

As shown in Table 3.2.2.1, the effect of the group variable on post-test scores was statistically significant ($F = 25.3$, $p < .001$). This indicates that there was a meaningful difference between the experimental and control groups after controlling for students' pre-test results. In other words, the teaching approach used in the experimental group had a statistically significant effect on students' post-test performance. The pre-test scores were also statistically significant ($F = 180.3$, $p < .001$), which confirms that students' initial level of knowledge strongly influenced their final results. Therefore, including pre-test scores as a covariate was necessary to ensure a more accurate comparison between the two groups.

Table 3.2.2.2. Post Hoc Comparison of Experimental and Control Groups – Lyceum

Post Hoc Comparisons - Group

Comparison							
Group		Group	Mean Difference	SE	df	t	p_{tukey}
Experimental	-	Control	1.80	0.357	34.0	5.03	<.001

The post hoc comparison presented in Table 3.2.2.2 shows that the experimental group outperformed the control group, with a mean difference of 1.80 ($p < .001$).

3.2.3 Results from the International School

Pre-test descriptive statistics were obtained prior to running the ANCOVA to provide an overview of students' performance prior to the treatment. These descriptive statistics served as a means through which to conduct an initial comparison of the experimental group and the control group, as well as help determine whether they are equivalent prior to the start of the experiment. Analysis of the pre-test scores gave some insight into the level of students' existing knowledge before receiving the treatment. The descriptive statistics for the pre-test and post-test scores of both the experimental and control groups for the International School sample are presented in Appendix 7 (p. 116).

Based on the descriptive statistics, there was only a slight variation in the mean scores between the control group and the experimental group before the test.

The results of the ANCOVA analysis for the international school are presented in Table 3.2.3.1 and Table 3.2.3.2.

Table 3.2.3.1. ANCOVA Results for Post-Test Scores – International School

ANCOVA - post test

	Sum of Squares	df	Mean Square	F	p
pre test	420.0	1	419.96	125.37	<.001
Group	33.0	1	33.03	9.86	.003
Residuals	113.9	34	3.35		

As shown in Table 3.2.3.1, the ANCOVA results indicate that the group variable had a statistically significant effect on students' post-test performance ($F = 9.86$, $p = 0.003$). This means that, after controlling for pre-test scores, the experimental group performed significantly differently from the control group. The pre-test scores were also significant ($F = 125.37$, $p < .001$), confirming a strong relationship between students' initial knowledge and their post-test results.

Table 3.2.3.2. Post Hoc Comparison of Experimental and Control Groups – International School

Post Hoc Comparisons - Group

Comparison							
Group		Group	Mean Difference	SE	df	t	p_{tukey}
Experimental	-	Control	1.89	0.602	34.0	3.14	.003

The post hoc comparison presented in Table 3.2.3.2 shows that the experimental group outperformed the control group, with a mean difference of 1.89 ($p = 0.003$).

Across all three schools, ANCOVA results showed a statistically significant group effect. After controlling for pre-test scores, the experimental groups achieved higher post-test results than the control groups. Initial differences between groups were also considered in the analysis.

3.3 Results of Reflective Feedback Survey (RQ3)

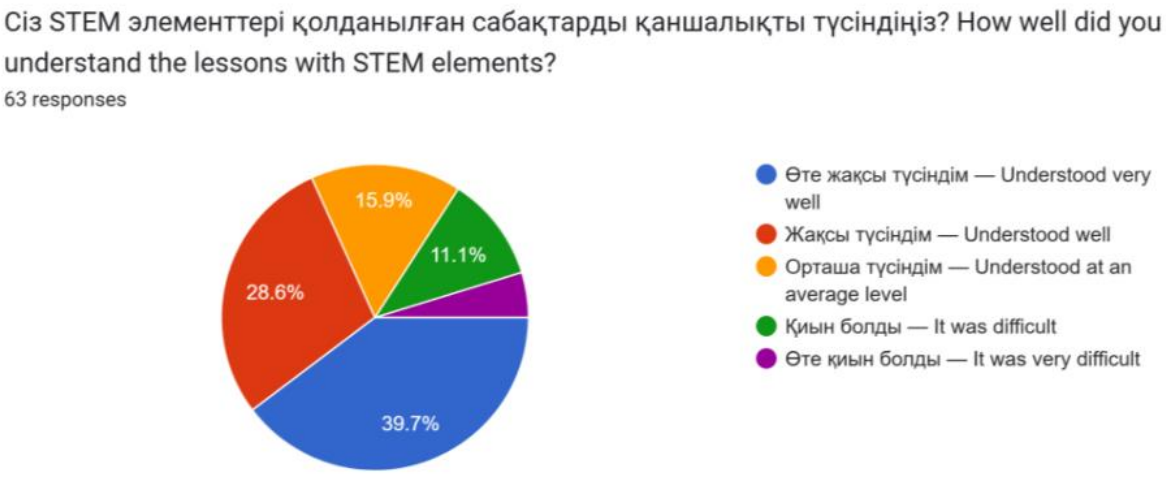
This section addresses Research Question 3, focusing on students' perceptions and challenges in STEM-integrated chemistry instruction. A reflective survey was conducted with 63 students from the experimental groups in three schools. The results show generally positive perceptions, including improved understanding and interest in chemistry, while time limits and complex tasks were the main challenges.

The reflective feedback survey results were analyzed using descriptive statistics to examine students' perceptions, understanding, interest, and challenges related to STEM instruction. The survey included 63 students from the experimental groups.

- Understanding of STEM-based lessons

Comprehension of lessons incorporating STEM concepts among the participants was relatively high. The highest proportion of students, representing 39.7% of respondents, claimed to have comprehended the lessons very well, while another 28.6% felt that the lessons had been comprehended well by them. 15.9% of the students had an average understanding of the lessons. The remaining 11.1% of students found the lessons to be difficult, whereas another 4.8% found them very difficult.

Figure 3.3.1. Students' level of understanding of STEM-integrated lessons

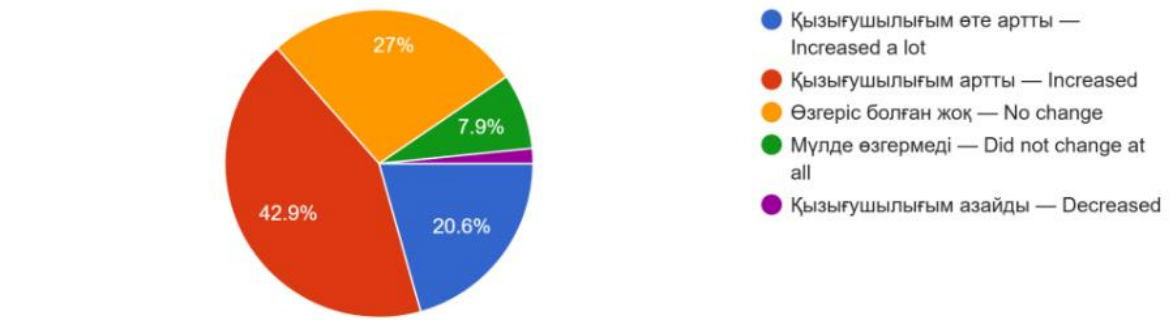


- Impact on students' interest in chemistry

The results indicate that STEM-integrated instruction had a positive effect on students' interest in chemistry. Specifically, 42.9% of respondents reported an increase in interest, including 20.6% who experienced a substantial increase. In contrast, 27%

reported no change, while only 7.9% indicated a decrease. These findings suggest that STEM integration enhanced students' engagement with the subject.

Figure 3.3.2. Impact of STEM-based lessons on students' interest in chemistry



- Challenges faced by students

Students reported several challenges during STEM-integrated lessons. The main issue was time constraints (28.6%), followed by difficulty understanding lesson content (19%), group work challenges (12.7%), and problems connecting chemistry with other STEM fields (9.5%). However, 30.2% of students reported no difficulties, as shown in Figure 3.3.3.

Figure 3.3.3. Challenges experienced during STEM-integrated lessons



- Students' preferences

Students' responses indicate that problem-solving assignments were the most preferred component of STEM-integrated lessons, accounting for 34.9% of all responses. This suggests that students particularly valued activities that involved critical thinking and the practical application of knowledge to real-world situations. Teamwork and interdisciplinary connections were also highly appreciated, each receiving 27% of responses. In contrast, individual work was the least preferred element, selected by only 11.1% of respondents. These findings highlight the importance of collaborative and application-oriented learning experiences within STEM education.

Figure 3.3.4. Students' preferred components of STEM-based lessons



The research provides an all-around examination of chemistry teaching through the integration of STEM principles from various angles. Results of content analysis shed light on effective teaching strategies and trends in STEM learning. The quantitative findings point out to differences in learning achievements of experimental and control groups. Moreover, the results of surveys highlight learners' views, understanding, interest in, and obstacles in STEM learning experiences.

DISCUSSION

In this chapter, the outcomes of the research will be discussed in relation to the research questions and prior research. The results obtained after analyzing the literature, conducting the pedagogical experiment, and collecting data through the reflective feedback survey will be analyzed to provide more insight into the success of STEM instruction in teaching chemistry. Special attention will be paid to the correlation between theoretical assumptions and practical results as well as to students' opinions and difficulties emerging while implementing STEM activities.

4.1 STEM Integration Methods and Trends in Chemistry Education

In addressing Research Question 1 — What STEM integration methods are used in chemistry instruction, and what trends can be identified in chemistry education research? — the qualitative content analysis of 30 peer-reviewed studies revealed that interdisciplinary approaches, problem-solving tasks, collaborative learning, and student-centered activities constitute the dominant instructional methods in STEM-integrated chemistry education. These findings are discussed below in relation to current theoretical frameworks and existing empirical evidence.

Based on an analysis of literature, it becomes clear that chemistry teaching in integration with STEM is mainly associated with interdisciplinary, problem-based, cooperative, and student-oriented methodologies. These educational techniques have been recognized as the ones which occur most often in the considered sources, therefore implying their importance in modern STEM researches.

Theory-wise, this is reflective of a general change within science education, from simply being content-based to becoming one that involves knowledge construction. Subsequent studies support this notion as well. For example, Bybee (2021) argues that STEM education must be able to go beyond disciplines and focus on situations in real-life that require the integration of knowledge. Likewise, Li et al. (2023) argue that interdisciplinarity and participation are among the key elements of current STEM education.

The results of the pedagogical experiment prove that these developments have both a practical and theoretical nature. At all three schools where the experiment was conducted, the introduction of interdisciplinary tasks, collaboration, and problem solving contributed to creating a learning environment consistent with the above-mentioned contemporary approaches. This consistency shows that there is an increasing tendency for the translation of STEM into actual education practices.

It is also essential to point out a nuance that should be considered. Despite the fact that the literature treats interdisciplinarity as a general component of STEM education, the introduction of this aspect varies from one case to another. For example, while interdisciplinary relations mostly involved biology and real-life settings in general high schools, in the lyceum, such relations involved physics and mathematics to a higher extent. It can be seen how this finding resonates with that proposed by Roehrig et al. (2021).

Yet another clear trend is the emphasis placed on problem solving and cooperation as core components of STEM education. These have been proven to be among the most effective tools for promoting learning and engaging students in classwork. In the current paper, similar tools were utilized in the form of collaborative work, problem solving assignments, and interdisciplinary work. The reason behind their effectiveness lies in the fact that they reflect the basic principles of constructivist theory of learning.

In addition, English (2023) emphasizes that problem-solving in STEM-related situations fosters the development of competencies that can be used across disciplines such as critical thinking and adaptive problem solving skills. The results of the present study confirm that students prefer problem solving activities and cooperative learning. In addition, it should be mentioned that many students became interested in chemistry because the interactive approach was applied successfully during classes, which affected their motivation positively. However, some students faced challenges in terms of understanding the tasks and managing time appropriately.

There is a difference in the recommendations made by theory and what happens in classroom settings, especially when it comes to digital technology and modeling. These two factors are generally considered vital for STEM education, but they were not seen in either literature or in practice as much as other aspects. This observation is consistent with that of Thibaut et al. (2021) who claim that technological and engineering aspects prove hard to implement in schools.

It is worth noting that recent studies have emphasized the importance of design problems in STEM-integrated chemistry instruction. According to Sheoratan et al. (2024), design-based projects in chemistry allow for the application of scientific knowledge and help develop students' creativity and skills to solve problems. As stated by the researchers, these types of tasks involve the learning of chemical concepts through the development of a solution to the existing problem, which is consistent with the major idea of STEM learning. Despite the presence of engineering designs in some tasks used in the present study, their use was not as extensive as that of other aspects of STEM.

From this analysis, one can say that interdisciplinary education, problem solving, collaboration, and student-centered teaching are among the main features of chemistry education incorporating STEM principles. They are always represented both in the scientific literature and classrooms, which proves both its theoretical and practical importance. At the same time, however, the analysis has shown that there is some imbalance in STEM incorporation due to the fact that engineering and technology are not represented to the same extent as science and math. Specifically, it was found that there are fewer engineering tasks implemented in classrooms compared to science or math tasks, which proves that engineering education is the hardest part of STEM.

4.2 Impact of STEM-Integrated Instruction on Students' Learning Outcomes and Engagement

In addressing Research Question 2 — What impact do commonly used STEM integration methods have on students' learning outcomes and engagement? — the ANCOVA results from all three school settings consistently demonstrated that students in the experimental groups achieved statistically significantly higher post-test scores

than those in the control groups, after controlling for pre-test performance. These quantitative findings are interpreted below in light of prior research on STEM-integrated instruction and student engagement.

The findings obtained from the quantitative data show that the inclusion of STEM in the teaching process has positively influenced the achievement levels of students regarding chemistry. In both schools, there was an increase in the post-test scores of students in the experimental group compared to those of the control group following the use of ANCOVA for adjusting the initial differences in scores among the two groups of learners. The findings reflect recent studies which suggest that integration of STEM enhances understanding through interdisciplinarity and engagement in learning activities (Li et al., 2023).

The importance of prior knowledge is one of the features of this study. There was a difference in pre-test results among different groups, but this was managed through the ANCOVA approach. The result is more credible due to this approach, confirming the idea that STEM integration has a positive impact on academic achievements. This perspective is shared in other research works that emphasize the key role of prior knowledge for learning results in a STEM setting (Roehrig et al., 2021).

In terms of academic performance, there is also evidence of a positive impact on engagement among the learners. Data from the surveys reveal that most learners became more interested in the subject of chemistry and preferred solving problems. This indicates that integration of STEM education positively impacts the students' level of engagement as well. According to English (2023), engagement in solving complicated problems helps develop higher-order thinking skills among the learners.

Meanwhile, the results point to the fact that the success of STEM teaching is dependent on its implementation strategy. While the majority of the students showed positive results, some had trouble understanding the tasks as well as managing their time. This can be interpreted as indicating that STEM teaching, although efficient, might be mentally challenging and should be accompanied by specific guidance. The

latter is in line with what other researchers point out regarding STEM education implementation (Thibaut et al., 2021).

In addition, the engineering design process can be considered another essential element in STEM-integrated education since it acts as a mediator between scientific literacy and actual problem-solving tasks. According to Lin et al. (2021), incorporating the engineering design process into STEM project-based instruction facilitates the formation of engineering thinking among students through repeated design, test, and refine iterations. The process allows students to use their chemistry knowledge and skills while developing essential competencies such as thinking, creating, and making decisions. Nevertheless, the integration of the engineering design process in classroom settings might prove complicated due to various reasons, including the time frame for teaching and a lack of adequate materials.

In summary, the research findings show that the positive impact of STEM-based learning did not depend on the context of schools involved in the experiment. Even with the variation in languages of instruction, demographic characteristics of students, and the amount of preexisting knowledge of STEM principles, similar trends were identified, indicating that STEM teaching strategies could be applied to diverse educational settings. Taken together, all the findings confirm the hypothesis about the significant impact of STEM-based learning on the achievement of learning goals and motivation of students. The combination of interdisciplinary approach, problem-solving skills, collaboration, and engineering design contribute to better comprehension and increased interest of learners.

4.3 Students' Challenges and Perceptions of STEM-Integrated Instruction

In addressing Research Question 3 — What challenges do students face, and how do they perceive STEM-integrated chemistry instruction in school classrooms? — the reflective feedback survey administered to 63 students from the experimental groups revealed predominantly positive perceptions of STEM-based lessons, alongside specific challenges related to time management and task complexity. The following

discussion interprets these findings in relation to students' engagement, motivation, and cognitive demands of interdisciplinary learning.

These findings suggest that overall students exhibited positive attitudes towards STEM-infused learning in terms of their knowledge of chemistry, interest in the subject, preferred way of learning, and difficulty perceptions. Students who felt very knowledgeable about what was taught in the classroom comprised a sizable proportion. This means that the integration of STEM into the teaching process not only facilitates surface knowledge acquisition but also allows for deeper learning concepts. It can be presumed that the involvement of cross-disciplinary tasks, problem solving, design engineering tasks, and collaboration contributed to the development of students' conceptual connections across contexts. This observation corroborates previous literature indicating the link between integrated STEM approaches and conceptual understanding (Li et al., 2023; Thibaut et al., 2021).

Based on students' answers, there is a clear increase in their interest in chemistry. Students stated that STEM-based teaching had increased both their interest in the lesson and its relevance, especially due to incorporating practical activities and applications of knowledge into the curriculum. This indicates that STEM education may have an effect on attitudes toward studying, because it makes abstract notions clearer and more relevant for students. Students' preferences also confirm this idea, as the most interesting parts of lessons are problem solving and group learning in addition to engineering projects. These results agree with English's opinion that active engagement is an important factor in maintaining motivation (2023).

Findings also help illustrate a number of problems faced by students. The issues frequently mentioned by participants relate to understanding difficult tasks and managing time effectively. Difficulties experienced by students indicate that, while STEM-infused education promotes deep learning, it also increases cognitive load and the necessity for good organization. Interdisciplinary tasks, engineering designs, and cooperative activities may be especially difficult for learners who are not accustomed to such educational practices yet. It supports the assumption that STEM education

requires complicated problem-solving that can only be achieved step-by-step through the development of certain cognitive abilities (English, 2023).

Yet another significant factor here is the connection between the level of student engagement and the difficulties experienced by the participants. While some learners identified obstacles, the latter did not affect their overall positive opinions of the lessons taught. Instead, the problems may be considered an inherent part of STEM education. If handled properly, they can lead to knowledge and skill acquisition. Yet, the results obtained make it clear that there is a need for proper instruction, involving task directions, time organization, and scaffolding.

Generally, the results show that students find STEM integration teaching method exciting, interesting, and beneficial to the learning process in chemistry. At the same time, from the mentioned challenges it can be concluded that the success of the use of the STEM approach heavily relies on the way it is being done. Thus, an equilibrium between cognition and assistance should be maintained.

Taken together, the findings of this study provide a coherent and mutually reinforcing set of answers to the three research questions, offering a comprehensive picture of STEM-integrated chemistry instruction in the Kazakhstan secondary school context. The three strands of evidence — qualitative content analysis, quasi-experimental quantitative data, and student reflective survey responses — converge on a consistent conclusion: integrating STEM principles into chemistry teaching yields measurable benefits for both academic achievement and student engagement, while also introducing specific pedagogical challenges that require deliberate instructional design.

The response to Research Question 1 established that the most prevalent STEM instructional methods in chemistry education are the interdisciplinary approach, problem-solving tasks, collaborative learning, and student-centered activities — all present in over 83% of the analyzed studies. This finding is theoretically significant, as it reflects a broader shift in the philosophy of science education: away from the transmission of isolated disciplinary content and toward the construction of integrated,

transferable knowledge (Kelley & Knowles, 2016; Thibaut et al., 2021). Notably, digital technologies and modeling — frequently cited in STEM literature as important tools — appeared far less consistently in practice, pointing to a persistent gap between theoretical recommendations and actual classroom implementation (Thibaut et al., 2021).

The response to Research Question 2 demonstrated that the instructional methods identified in the literature analysis produced statistically significant improvements in student achievement when applied in real classroom settings. Across all three schools — a general secondary school, a lyceum, and an international school — students in the experimental groups consistently outperformed their counterparts in the control groups in post-test scores, with mean differences ranging from 1.80 to 1.89 points after ANCOVA adjustment. This consistency across three institutionally and linguistically distinct settings strengthens the external validity of the findings and suggests that the benefits of STEM-integrated instruction are not context-specific but may be applicable across a range of educational environments. These results are in line with the research hypothesis (H_1) formulated at the outset of the study, confirming that STEM-integrated instruction leads to significantly better learning outcomes compared to traditional teaching methods.

The response to Research Question 3 added an important qualitative dimension to this picture by revealing how students themselves experienced STEM-integrated instruction. The majority of students reported positive perceptions, including improved understanding of chemistry content and increased motivation to learn. However, a notable proportion of students also identified time constraints and difficulty understanding interdisciplinary tasks as significant challenges. These challenges are not incidental — they reflect the inherently higher cognitive demand of integrated, problem-based learning compared to traditional instruction (English, 2023). Importantly, rather than undermining the effectiveness of the approach, these difficulties point to the conditions under which STEM integration is most likely to

succeed: namely, when sufficient instructional scaffolding, time allocation, and task structuring are in place (Roehrig et al., 2021).

Viewed collectively, the findings of this study affirm the value of STEM-integrated chemistry instruction as both a theoretically grounded and empirically supported pedagogical approach. The alignment between what the literature identifies as effective practice (RQ1), what the experimental data demonstrates in terms of learning outcomes (RQ2), and what students report about their experiences (RQ3) creates a coherent and robust evidence base. This coherence also reflects the importance of adopting a mixed-methods research design: had only quantitative data been collected, the nuance of student challenges and perceptions — critical for practical implementation — would have remained invisible. Conversely, had only qualitative analysis been conducted, the measurable impact on achievement could not have been established. Together, the three research strands provide a fuller and more actionable understanding of how, why, and under what conditions STEM integration benefits chemistry learners in the Kazakhstan secondary school context.

CONCLUSION

This study investigated the integration of chemistry instruction with other STEM disciplines. A mixed-methods research design was used, including qualitative content analysis, a quasi-experimental intervention, and a student reflective feedback survey. The findings show that the aim of the study was achieved. STEM-integrated instruction was found to be an effective and meaningful approach to chemistry education.

The qualitative content analysis identified the most common methods used in STEM-integrated chemistry instruction. These included interdisciplinary approaches, problem-solving tasks, collaborative learning, engineering design tasks, project work, inquiry activities, and student-centered learning. These findings provided a theoretical basis for the classroom intervention. They also confirmed the importance of active and interdisciplinary teaching strategies in chemistry education.

The quantitative results showed that STEM-integrated instruction had a positive effect on students' academic achievement. Across three schools in Almaty, Kazakhstan, the experimental groups achieved higher post-test results than the control groups. This difference remained significant after controlling for pre-test performance. Therefore, the results support the alternative hypothesis of the study. They confirm that students taught through STEM-integrated instruction performed better than students taught through traditional methods.

The reflective feedback survey showed that students generally perceived STEM-integrated lessons positively. Many students reported better understanding, increased interest in chemistry, and preference for problem-solving and collaborative activities. However, some challenges were also identified. These included limited time, task complexity, and difficulties in connecting chemistry with other STEM disciplines.

Overall, the findings suggest that STEM-integrated chemistry instruction can improve students' academic performance, engagement, motivation, and problem-solving skills. However, successful implementation requires careful lesson planning, appropriate scaffolding, sufficient time allocation, teacher readiness, and institutional support. Chemistry teachers should receive targeted professional development in

STEM lesson design. Curriculum developers should allocate more space for interdisciplinary and real-world projects. Educational policymakers should support schools through better access to digital tools, modeling resources, and laboratory infrastructure.

Future research should involve larger and more diverse samples. It should also include longer intervention periods and longitudinal designs. This would help examine the long-term effects of STEM-integrated instruction on students' chemistry achievement, motivation, and attitudes toward science.

LIMITATIONS

Despite the contributions of the present study, several methodological limitations must be acknowledged.

First, the qualitative content analysis was based on a purposefully selected corpus of 30 peer-reviewed articles. Although studies were systematically filtered according to predefined inclusion criteria, this sample size may not fully capture the breadth of existing empirical work on STEM-integrated chemistry instruction.

Second, the quantitative phase was confined to ninth-grade students from three schools in Almaty, Kazakhstan. Restricting the sample to a single grade level limits the transferability of the findings, as cognitive development and responsiveness to instructional approaches may differ across age groups.

Third, the reflective feedback survey was administered solely to students from the experimental groups, as by design it targeted only those who had undergone STEM-integrated instruction. The relatively small size of this sample ($n = 63$) limits the extent to which these findings can be generalized to broader student populations.

Fourth, the study was conducted within a geographically bounded context. Although three distinct school types were included, the findings may not be representative of the full spectrum of educational settings in Kazakhstan or comparable national contexts.

Finally, the instructional intervention spanned approximately three weeks, which was sufficient for detecting short-term effects but does not permit conclusions regarding the long-term durability of learning gains. Longitudinal research designs would be required to address this gap.

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APPENDICES

Appendix 1

Table A1.1. Sample of research articles on STEM integration in chemistry education (2020–2025)

№	Author(s), year	Title	Aim
1	Bunyamin, M. A. H., Talib, C. A., Ahmad, N. J., Ibrahim, N. H., & Surif, J., 2020.	Current Teaching Practice of Physics Teachers and Implications for Integrated STEM Education.	To characterize the current teaching practices of physics teachers and examine how these practices relate to the principles of integrated STEM education, in order to inform future implementation of integrated STEM teaching in schools.
2	Özkul, H., & Özden, M., 2020.	Investigation of the Effects of Engineering-Oriented STEM Integration Activities on Scientific Process Skills and STEM Career Interests: A Mixed Methods Study.	To investigate the effects of engineering-oriented integrated STEM activities on middle school students' scientific process skills and their interest in STEM careers using a mixed-methods research design.
3	Shukri, A. A. M., Ahmad, C. N. C., & Daud, N., 2020.	Integrated STEM-based module: Relationship between students' creative thinking and science achievement.	To explore the relationship between students' creative thinking and science achievement through the implementation of an integrated STEM-based module on the topic of Reproduction.
4	Wang, H.-H., Charoenmuang, M., Knobloch, N. A., & Tormoehlen, R. L., 2020.	Defining interdisciplinary collaboration based on high school teachers' beliefs and practices of STEM integration using a complex designed system.	To investigate high school teachers' beliefs and instructional practices regarding STEM integration and to define a model of interdisciplinary collaboration for implementing integrated STEM instruction within complex educational systems.
5	Yang, D., & Baldwin, S. J., 2020.	Using Technology to Support Student Learning in an Integrated	To examine how different technology-use strategies can support student learning in integrated STEM learning environments and to

		STEM Learning Environment.	illustrate ways technology can facilitate interdisciplinary learning, inquiry, and problem-solving across STEM disciplines.
6	Awad, N., 2021.	Exploring STEM integration: assessing the effectiveness of an interdisciplinary informal program in fostering students' performance and inspiration.	The aim of this study is to investigate the effectiveness of an informal interdisciplinary STEM program (Sound, Waves and Communication Systems – SWCS) on middle school students' achievement and motivation, and to identify factors that influence these outcomes.
7	Dare, E. A., Keratithamkul, K., Hiwatig, B. M., & Li, F., 2021.	Beyond Content: The Role of STEM Disciplines, Real-World Problems, 21st Century Skills, and STEM Careers within Science Teachers' Conceptions of Integrated STEM Education.	To investigate science teachers' conceptions of integrated STEM education, particularly how they understand the role of STEM disciplines, real-world problems, 21st-century skills, and STEM careers after participating in professional development and implementing integrated STEM lessons in their classrooms.
8	De Meester, J., De Cock, M., Langie, G., & Dehaene, W., 2021.	The Process of Designing Integrated STEM Learning Materials: Case Study towards an Evidence-based Model.	To examine how teachers collaboratively design integrated STEM learning materials and to develop an evidence-based model describing the process and principles for creating effective interdisciplinary STEM learning units in secondary education.
9	Isdianti, M.F., Nasrudin, H., & Erman, E. (2021)	The Effectiveness of STEM-Based Inquiry Learning Packages to Improving Students' Critical Thinking Skill	The aim of the study was to determine the effectiveness of STEM-based inquiry learning packages on simple machine (lever) topics in improving junior high school students' critical thinking skills.
10	Nurmaliah, C., Azmi, T. N., Safrida, Khairil, & Artika, W., 2021.	The impact of implementation of STEM integrating project-based learning on students' problem-solving abilities.	To examine the effect of integrated STEM education combined with project-based learning on senior high school students' problem-solving abilities.

11	Hamad, S.; Tairab, H.; Wardat, Y. et al. 2022.	Understanding Science Teachers' Implementations of Integrated STEM: Teacher Perceptions and Practice	To explore teachers' perceptions, practices, and challenges of STEM implementation.
12	Han, J., Kelley, T., & Knowles, J. G., 2022.	Building a sustainable model of integrated STEM education: investigating secondary school STEM classes after an integrated STEM project.	To investigate how secondary school teachers implement integrated STEM instruction after the completion of a funded STEM project and to examine its impact on students' STEM knowledge and twenty-first century skills.
13	Hasibuan, M. P.; Sari, R. P.; Syahputra, R. A.; Nahadi. 2022.	Application of Integrated Project-based and STEM-based E-learning Tools to Improve Students' Creative Thinking and Self-Regulation Skills	To develop and apply integrated project-based and STEM-based e-learning tools in order to improve students' creative thinking skills and self-regulation.
14	McLure, F.; Tang, K.-S.; Williams, P. J. 2022.	What do integrated STEM projects look like in middle school and high school classrooms? A systematic literature review of empirical studies of iSTEM projects.	To systematically analyze empirical studies of integrated STEM (iSTEM) projects in secondary education in order to identify their characteristics, examine how STEM domains are integrated, and evaluate the extent to which these projects reflect features of effective STEM practices.
15	Wilkerson, J. R.; Schorr, M. T.; Peltz, B. C. 2022.	An Analysis of Teacher-Developed Integrated STEM Project-Based Instruction (PBI) Curriculum Units.	To analyze teacher-developed integrated STEM project-based instruction (PBI) curriculum units in elementary and middle school in order to identify their strengths and weaknesses in terms of STEM integration and PBI design.
16	Dibyantini, R.E., Amdayani, S., Siregar, M.I., &	Application of STEM-PjBL Based Chemistry Module to Improve Science Literacy and	To determine the application of a STEM-PjBL-based chemistry module in improving science literacy and student learning motivation among

	Syafriani, D., 2023.	Student Learning Motivation.	second-semester general chemistry students (organic compounds).
17	Gusman, T.A., Novitasari, & Yulina, I.K. (2023).	The Effect of STEM Integrated Problem-Based Learning Model on Students' Critical Thinking Skills on Electrolyte and Non-Electrolyte Solution Materials.	To determine the effect of the STEM-integrated Problem-Based Learning (STEM-PBL) model on students' critical thinking skills in learning electrolyte and non-electrolyte solution materials.
18	Media Roza, Lufri, Asrizal. 2023.	Meta-Analysis the Effect of STEM Integrated Problem Based Learning Model on Science Learning Outcomes.	The study aims to analyze the impact of STEM-integrated Problem-Based Learning (PBL) on science learning outcomes by conducting a meta-analysis of 22 selected studies published between 2017–2021. Specifically, it seeks to determine the magnitude of effect (effect size) across different educational levels, subject areas, and types of learning outcomes (e.g., critical thinking, scientific literacy, creativity).
19	Sarıoğlan, A.B., & Şentürk Özkaya, Ö. (2023).	Web Integrated STEM Learning: Effects on Students' Academic Achievement, Creativity and Metacognitive Awareness.	To investigate the effects of Web-integrated STEM learning based on the STEM Cycline model on seventh-grade students' academic achievement, scientific creativity, and metacognitive awareness in the topic of Force and Energy.
20	Sulaiman, F., Rosales Jr., J.J., & Lee, J.K., 2023.	The effectiveness of the integrated STEM-PBL physics module on students' interest, sense-making and effort.	To examine the effectiveness of an integrated STEM-PBL physics module in improving secondary school students' personal interest and sense-making & effort in learning classical mechanics.
21	AlAli, R., 2024.	Enhancing 21st Century Skills Through Integrated STEM Education Using Project-Oriented Problem-Based Learning.	To examine the impact of integrated STEM education using Project-Oriented Problem-Based Learning on the development of students' 21st-century skills.

22	Fitriyana, N.; Wiyarsi, A.; Pratomo, H.; Marfuatun, M. 2024.	The Importance of Integrated STEM Learning in Chemistry Lesson: Perspectives from High School and Vocational School Chemistry Teachers.	To investigate and compare high school and vocational school chemistry teachers' perspectives, knowledge, and experiences regarding the implementation of integrated STEM learning in chemistry lessons, and to evaluate its potential and challenges in practice.
23	Ismail, M. H.; Fadzil, H. M.; Mat Salleh, M. F.; Saat, R. M.; Kurniawan, C.; Hariyono, E. 2024.	Science Teachers' Instructional Practices: A Need Analysis for Preparing Integrated STEM Practices through Scientist-Teacher-Student Partnership.	To investigate science teachers' instructional practices in integrating STEM in classrooms and to identify their needs for improving integrated STEM teaching through a Scientist-Teacher-Student Partnership (STSP) approach.
24	Ningtyas, P. K.; Widarti, H. R.; Parlan, P.; Rahayu, S.; Dasna, I. W.2024.	Enhancing Students' Abilities and Skills through Science Learning Integrated STEM: A Systematic Literature Review.	To systematically review and analyze the effectiveness of integrated STEM approaches in science learning, focusing on how STEM implementation improves students' abilities and skills, as well as identifying the learning models and media used in STEM-integrated instruction
25	Simanjuntak, Y. I. W.; Purwaningsih, D. 2024.	STEM Integrated Problem Based Learning: The Implementation and Roles in Science Learning.	To systematically review how STEM-integrated Problem-Based Learning (PBL) is implemented in science education and to examine its roles in improving students' skills and learning outcomes across different science subjects
26	Haleda, P.; Isa, I.; Munandar, H.; Bialangi, N.; Tangio, J. S.; Thayban; Kurniawati, E. 2025.	The Effect of STEM Integrated Project Based Learning Model on Students' Collaboration Skills in Atomic Structure.	To investigate the effect of a STEM-integrated Project-Based Learning (PjBL) model on students' collaboration skills in learning atomic structure using a quasi-experimental design with control and experimental groups.
27	Nipyrakis, A.; Stavrou, D.;	Examining S-T-E-M Teachers' Design of	To examine how in-service secondary STEM teachers design integrated STEM lesson plans within a professional development program,

	Avraamidou, L. 2025.	Integrated STEM Lesson Plans.	with a focus on identifying which key STEM characteristics they incorporate, how they structure instructional activities, and how disciplinary and interdisciplinary elements are integrated in their teaching designs.
28	Setiawan, V. R.; Situmorang, M.; Silaban, R. 2025.	Project-based learning with STEM to promote higher order thinking skills as a strategy to improve high school chemistry learning outcomes.	o develop and implement a STEM-integrated Project-Based Learning (PjBL-STEM) model in high school chemistry (electrochemistry) in order to enhance students' Higher Order Thinking Skills (HOTS) and improve learning outcomes through active, project-based learning experiences.
29	Shagrayeva, B.; Shertayeva, N.; Zhorabekova, A.; Baymakhanova, G.; Toktamys, N. 2025.	Enhancing the Quality of Education Through the Integration of STEM Technology Elements in Chemistry Lessons.	To design and implement a STEM-integrated, project-based learning approach in chemistry (focused on a "Water Purification Methods" project) and evaluate its effectiveness in improving students' engagement, interest, and research skills through experimental and data-driven analysis.
30	Toktamys, N.B., Shagrayeva, B.B., Shertayeva, N.T., & Bitemirova, A.E., 2025.	Study of the Impact of Integrating STEM Technology into Chemistry Teaching on Students' XXI Century Skills.	To evaluate the effectiveness of integrating STEM technology into 10th-grade chemistry teaching and to compare its impact on students' twenty-first century skills using a quasi-experimental control-group design.

Table A1.2. Implementation of STEM instructional methods and activities in selected studies

№	Authors	Activities
1	Han, J., Kelley, T., & Knowles, J. G., 2022	In this study, hands-on laboratory activities were implemented through field-based investigations and prototype testing. Inquiry activities were reflected in students' formulation of research questions, data collection, and evidence-based conclusions. Engineering design tasks involved iterative processes of designing, testing, and improving 3D-printed

		prototypes supported by digital modeling and simulations. Collaborative learning was emphasized through group-based decision-making, while interdisciplinary tasks integrated biology, engineering, mathematics, and technology. Data collection and analysis were used to interpret field observations and learning outcomes, and student-centered learning was promoted by allowing learners to actively plan, design, and manage their learning processes.
2	AlAli, R., 2024.	The study implemented integrated STEM instruction through project-oriented problem-based learning. Hands-on activities were used in the creation and improvement of project artifacts. Problem-solving tasks required students to address real-world STEM problems. Engineering design tasks followed an iterative design process (Think–Make–Improve). Learning activities were organized as projects integrating multiple STEM disciplines. Collaborative learning was applied through structured group work. Data collection and analysis were conducted using pre- and post-tests to evaluate learning outcomes. Student-centered learning was ensured by allowing students autonomy in project planning and execution.
3	Nurmaliah, C., Azmi, T. N., Safrida, Khairil, & Artika, W., 2021.	The study implemented integrated STEM instruction through project-based learning. Students completed hands-on activities while creating an antiviral disinfectant spray. Problem-solving tasks focused on addressing real-life health issues. Engineering design tasks followed an engineering design loop to develop and improve the product. Learning activities were carried out collaboratively in groups and integrated science, technology, engineering, and mathematics concepts. Students played an active role in planning and carrying out the project.
4	Awad, N., 2021.	The SWCS program included unique hands-on activities such as exploring sound waves, building simple communication systems, and working with technological devices related to acoustics. Students completed interdisciplinary project tasks that required solving real-world problems connected to sound and communication. ICT tools were used to support these activities, and students worked collaboratively in groups within a student-centered learning environment. The program concluded with students presenting the outcomes of their projects.
5	Özkul, H., & Özden, M., 2020.	The study implemented engineering-oriented integrated STEM through hands-on mini-projects such as *Let's Make a Thermos*, *Protecting my Pelicans*, *Earthquake Resistant Buildings*, *Sea Boat*, *Storm Resistant Tower*, *Electric Car*, and *We do Coding*. Each activity addressed a real-

		world problem and followed a full engineering design cycle, requiring students to build, test, and improve prototypes. Learning was interdisciplinary and collaborative, with students collecting measurements, evaluating results, and justifying their design decisions. The approach was student-centered and concluded with group discussion and presentation of solutions.
6	Toktamys, N.B., Shagrayeva, B.B., Shertayeva, N.T., & Bitemirova, A.E., 2025.	Integrated STEM was implemented through hands-on, project-based chemistry activities such as designing eco-friendly synthesis processes, constructing small-scale calorimeters to study heat transfer, developing convection models, and completing the Solar Oven STEM Challenge. These tasks required real-world problem-solving and the development and testing of energy-efficient prototypes within an interdisciplinary framework. Students worked collaboratively, analyzed experimental results, made design decisions, and presented their project outcomes using the Cambridge assessment criteria.
7	Dibyantini, R.E., Amdayani, S., Siregar, M.I., & Syafriani, D., 2023.	The study implemented an integrated STEM-PjBL module in organic chemistry structured around project-based, real-world problem-solving tasks. Learning was interdisciplinary and collaborative, with students working in teams within a student-centered environment. A distinctive feature of the module was the use of PISA-based science literacy components—Explaining Scientific Phenomena (ESP), Identifying Scientific Issues (ISI), and Using Scientific Evidence (USE)—through which students analyzed data and applied evidence-based reasoning.
8	Gusman, T.A., Novitasari, & Yulina, I.K., 2023.	The study implemented STEM-integrated PBL through hands-on activities on electrolyte and non-electrolyte solutions, centered on designing and constructing an *electrolyte testing device*. Students solved real-world problems, conducted experiments, analyzed results, and drew evidence-based conclusions. Learning was interdisciplinary, collaborative, and student-centered, with group discussions supporting critical thinking development.
9	Sulaiman, F., Rosales Jr., J.J., & Lee, J.K., 2023.	The integrated STEM-PBL module was implemented through two hands-on projects, Egg Drop Project and Spaghetti Bridge Project, where students collaboratively solved real-world engineering problems. They followed an engineering design process by generating ideas, building and testing prototypes, collecting and analyzing measurements, and refining their designs. The activities integrated physics with engineering and

		mathematics, promoted sustained inquiry and student-centered learning, and concluded with discussion and presentation of the final products.
10	Sarıoğlan, A.B., & Şentürk Özkaya, Ö., 2023.	The Web-integrated STEM learning model (STEM Cycline) was implemented through authentic problem-based projects in the topic of Force and Energy, where students collaboratively designed and constructed physical prototypes such as equal-arm balances, dynamometers, spring systems, friction-reducing rockets, and energy investigation devices. Learners used Tinkercad for 3D modeling and 3D printing, as well as pHet and Crocodile Physics simulations to explore and test scientific concepts. The activities followed an iterative engineering design process involving data collection, measurement, analysis, redesign, and presentation of products using Web 2.0 tools such as Canva and Kahoot, integrating science, technology, engineering, and mathematics in a fully student-centered framework.
11	Wang, H.-H., Charoenmuang, M., Knobloch, N. A., & Tormoehlen, R. L., 2020.	Integrated STEM learning was implemented through a hydroponics project, where students investigated plant growth conditions and determined factors such as the temperature required for basil growth. Students conducted hands-on experiments, collected and analyzed data, and applied scientific knowledge to solve real-world problems. The activities integrated biology, engineering concepts, and environmental considerations through collaborative, student-centered inquiry.
12	Yang, D., & Baldwin, S. J., 2020.	In this study, integrated STEM learning is supported through technology-enhanced activities that connect multiple STEM disciplines. Students engage in web-based inquiry environments such as WISE to investigate real-world problems like airbag safety and climate change. Additional examples include computer-based air pollution modeling (APoMT), virtual laboratory simulations, and robotics or satellite-programming projects, where students design and test technological solutions while integrating science, mathematics, engineering, and technology.
13	Bunyamin, M. A. H., Talib, C. A., Ahmad, N. J., Ibrahim, N. H., & Surif, J., 2020.	In this study, elements of integrated STEM learning were implemented through practical physics activities. Students conducted a hands-on experiment on Archimedes' principle to investigate buoyant force and differences in weight in water and air. A distinctive activity involved constructing a liquid pressure model using a plastic bottle with holes at different heights to demonstrate how pressure changes with depth. These activities were connected to real-world applications such as ships, dams,

		and airplanes, helping students relate physics concepts to engineering and technological systems.
14	Shukri, A. A. M., Ahmad, C. N. C., & Daud, N., 2020.	The implementation of an integrated STEM-based module engaged students in collaborative problem solving related to the topic of human reproduction. Learning activities included engineering design tasks, model construction, and project-based investigations, where students analyzed information, generated solutions, and communicated their ideas. These activities integrated science with engineering and technological perspectives while promoting creative thinking and interdisciplinary STEM understanding.
15	De Meester, J., De Cock, M., Langie, G., & Dehaene, W., 2021.	The development of integrated STEM learning materials was organized around a central student challenge that required learners to solve complex, real-world problems by integrating knowledge from science, technology, engineering, and mathematics. The designed learning units consisted of a sequence of subproblems, each introduced through a teaser and supported by theoretical explanations, experiments, or practical tasks that guided students toward a solution. Through these interdisciplinary activities, students engaged in inquiry, problem solving, and collaborative learning while connecting concepts across multiple STEM disciplines within a coherent project-based learning structure.
16	Dare, E. A., Keratithamkul, K., Hiwatig, B. M., & Li, F., 2021.	The study explores teachers' conceptions of integrated STEM education after implementing STEM lessons in their classrooms. Teachers highlighted the use of real-world problems to connect science, technology, engineering, and mathematics while fostering 21st-century skills such as critical thinking and collaboration. The findings also emphasize the role of integrated STEM instruction in increasing students' awareness of STEM careers and real-life applications of scientific knowledge.
17	Isdianti, M.F., Nasrudin, H., & Erman, E., 2021.	In the study by Isdianti, Nasrudin, and Erman (2021), an integrated STEM-based inquiry approach was used to improve students' critical thinking in learning simple machines. The learning activities included analyzing the excavator mechanism, using the PhET "Balancing Act" simulation to model lever systems and mechanical advantage, and identifying lever applications in everyday tools. Students also analyzed and designed simple technologies based on lever principles, connecting science concepts with real-world engineering contexts.

18	Hamad, S.; Tairab, H.; Wardat, Y. et al., 2022.	Hamad et al. (2022) is distinctive in that it examines STEM integration through teachers' real classroom experiences rather than theoretical models. The study employs an exploratory sequential mixed-method design, combining interviews with a follow-up survey to strengthen validity. It also focuses on the UAE context, where STEM implementation is still developing, and highlights that challenges are mainly due to external factors such as lack of support and guidelines rather than teachers' competencies.
19	McLure, F.; Tang, K.-S.; Williams, P. J., 2022	This study is unique in that it systematically reviews iSTEM projects and reveals inconsistencies in how STEM integration is implemented across studies. It highlights the limited use of engineering design, the weak integration of mathematics and technology, and a gap between theoretical frameworks and actual classroom practice. The article also emphasizes the lack of student agency and contextual relevance in many projects, while pointing out that most research focuses on outcomes rather than the processes of integration, indicating important directions for future research.
20	Wilkerson, J. R.; Schorr, M. T.; Peltz, B. C., 2022.	This study is distinctive in that it analyzes teacher-developed integrated STEM project-based instruction (PBI) curriculum units, rather than externally designed or researcher-led interventions. Its key contribution lies in evaluating the quality of real classroom-ready materials, revealing gaps between intended STEM integration and actual curriculum design. The study highlights inconsistencies in how STEM components, particularly engineering and mathematics, are incorporated, and shows that while PBI structures are present, the depth of integration often remains limited. By focusing on authentic teacher-created units, the article provides practical insights into how STEM is implemented in everyday educational practice and identifies areas for improving curriculum design.
21	Hasibuan, M. P.; Sari, R. P.; Syahputra, R. A.; Nahadi., 2022.	This study is distinctive in that it integrates project-based learning (PjBL), STEM, and e-learning into a single instructional model, reflecting a modern, technology-enhanced approach to education. Its key contribution lies in focusing not only on academic achievement but also on the development of higher-order skills, particularly creative thinking and self-regulation. Unlike many STEM studies centered on classroom practices, this research emphasizes digital learning environments, highlighting how online tools can support active, student-centered learning. Additionally, it demonstrates how structured PjBL-STEM frameworks can foster

		independent learning and metacognitive skills, making it especially relevant in the context of post-pandemic education.
22	Media Roza, Lufri, Asrizal., 2023.	This study is distinctive for its meta-analytical design, synthesizing 22 empirical studies to provide a quantitative evaluation of STEM-integrated PBL in science education. It identifies variations in effectiveness across educational levels, subjects, and learning outcomes, with an overall high effect size (ES = 1.036) . Unlike single-intervention studies, it offers more generalizable evidence and highlights the strong impact of STEM-PBL on scientific literacy, critical thinking, and other higher-order skills, while also revealing patterns in how these outcomes differ by context.
23	Ningtyas, P. K.; Widarti, H. R.; Parlan, P.; Rahayu, S.; Dasna, I. W., 2024.	This study is distinctive in that it provides a comprehensive synthesis of 35 empirical studies, offering a broad and structured overview of how integrated STEM is implemented in science education. Unlike narrower reviews, it not only evaluates effectiveness but also systematically maps the variety of instructional models (e.g., PjBL, PBL, 6E, Jigsaw) and learning media (e.g., virtual labs, AR, interactive videos) used in STEM contexts . A key contribution of the study is its detailed classification of student outcomes, demonstrating that STEM integration enhances a wide range of skills, including 4C competencies, scientific literacy, and ICT literacy. This makes the article particularly valuable for understanding both the pedagogical diversity and multidimensional impact of STEM in science learning.
24	Ismail, M. H.; Fadzil, H. M.; Mat Salleh, M. F.; Saat, R. M.; Kurniawan, C.; Hariyono, E., 2024.	This study is distinctive in that it employs a qualitative need analysis to examine real classroom practices of science teachers rather than evaluating a specific intervention. Its key contribution lies in revealing the gap between intended STEM integration and actual instructional practices, showing that although teachers use inquiry, problem-based learning, and hands-on activities, their approaches remain largely teacher-centered. The study also highlights teachers' limited ability to connect STEM disciplines and their need for professional support. A unique aspect is the proposed Scientist-Teacher-Student Partnership (STSP) as a practical solution to enhance teachers' pedagogical skills and promote more effective and authentic STEM integration.
25	Simanjuntak, Y. I. W.; Purwaningsih, D., 2024.	This study is distinctive in that it provides a detailed, phase-by-phase description of STEM-integrated Problem-Based Learning (PBL), explicitly mapping STEM components onto all five stages of the PBL process. Unlike many review studies, it goes beyond general conclusions

		by explaining how instructional activities are implemented in practice, including experiments, engineering design, use of technology, and student presentations. A key unique feature is its demonstration of how STEM disciplines are systematically embedded throughout the entire learning cycle, rather than treated as separate elements. This makes the study particularly valuable as a practical framework for designing and implementing integrated STEM instruction in science education.
26	Fitriyana, N.; Wiyarsi, A.; Pratomo, H.; Marfuatun, M., 2024.	The implementation of an integrated STEM approach in chemistry education is examined through both teachers' perceptions and their reported classroom practices, providing a nuanced understanding of its real-world application. While teachers demonstrate generally positive attitudes and a clear conceptual awareness of STEM, their implementation is often limited and fragmented, relying on isolated activities rather than structured instructional models. A distinctive feature of the study is the comparison between high school and vocational teachers, which reveals similar perceptions despite differing educational contexts. These findings highlight a persistent gap between theoretical understanding and practical readiness in applying integrated STEM in chemistry teaching.
27	Shagrayeva, B.; Shertayeva, N.; Zhorabekova, A.; Baymakhanova, G.; Toktamys, N., 2025.	The implementation of an integrated STEM approach in chemistry education is distinguished by a project-based model that combines experimentation, engineering design, and digital technologies within a single learning process. A key feature is the use of real-time data analysis through sensors and ReLab software, enabling students to interpret chemical changes during experiments . The study presents a fully integrated STEM cycle, where students design, test, and optimize solutions, making it a strong example of authentic STEM instruction.
28	Haleda, P.; Isa, I.; Munandar, H.; Bialangi, N.; Tangio, J. S.; Thayban; Kurniawati, E., 2025.	The implementation of a STEM-integrated Project-Based Learning approach in this study is distinguished by its explicit focus on developing students' collaboration skills as the primary learning outcome. Rather than emphasizing content mastery alone, the study systematically evaluates five dimensions of collaboration—cooperation, responsibility, communication, flexibility, and compromise—within the learning process . A notable feature is the structured integration of STEM-PjBL phases (research, discovery, application, and communication), which provides a clear pedagogical framework for fostering teamwork. This makes the study particularly valuable for demonstrating how STEM approaches can

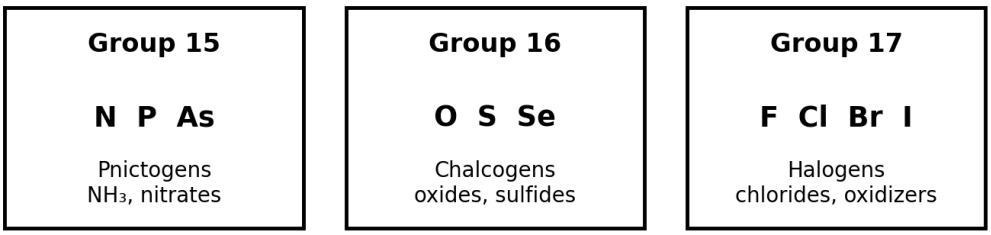
		be used to target specific 21st-century competencies, especially collaborative learning in complex chemistry topics like atomic structure.
29	Setiawan, V. R.; Situmorang, M.; Silaban, R., 2025.	The implementation of a STEM-integrated Project-Based Learning model in this study is notable for its systematic integration of project work, experimental activities, and higher-order thinking skills (HOTS) within real classroom practice. A distinctive feature is the use of the ADDIE-based development and validation process, ensuring the model's consistency and scalability across schools . The study also clearly demonstrates the link between structured project activities and improved learning outcomes, making it a strong example of evidence-based STEM instruction in chemistry education.
30	Nipyrakis, A.; Stavrou, D.; Avraamidou, L., 2025.	The implementation of integrated STEM in this study is examined through teachers' lesson design practices rather than classroom outcomes, offering insight into how STEM instruction is planned. A key feature is the use of a learning community within a professional development program, where teachers collaboratively design and reflect on lesson plans. The study also applies the boundary objects framework to reveal how disciplinary backgrounds influence interdisciplinary integration and instructional design.

Appendix 2

Pre-test for General secondary school

Unit: "Group 17, 16, and 15 Elements and Their Compounds"

Chemistry: Grade 9



p-block elements: trends, compounds and reactions

Student full name: _____
Grade: _____ Date: _____
Time allowed: 25 minutes Total: 21 marks

Learning Objectives

• Predict trends in the properties of Group 17 elements.
• Describe the chemical properties of chlorine and halide displacement reactions.
• Describe the general properties of Group 16 elements and their compounds.
• Explain the formation and environmental effects of acid rain.
• Describe key properties and compounds of Group 15 elements, including nitrogen and ammonia.
• Write and balance chemical equations for selected reactions of Groups 15, 16 and 17 elements.

Assessment Criteria

• Completes statements about trends in Group 17 and Group 15 elements.
• Writes correct balanced equations for reactions involving chlorine and nitrogen compounds.
• Compares properties of Group 16 elements using a table.
• Explains acid rain formation and effects.
• Identifies properties and reactions of ammonia and ammonium salts.
• Solves a stoichiometric calculation using a balanced equation.
Thinking Skills Level: Knowledge and Understanding; Application

Tasks

1. Fill in the gaps. [3]

Complete the statements using the appropriate words.

a) In Group 17, from fluorine to iodine, the melting and boiling points _____.

b) As the atomic number increases down Group 17, the oxidizing ability _____.

c) Group 15 elements are also called _____.

2. Write balanced chemical equations. [5]

Chlorine and nitrogen take part in important reactions. Complete and balance the equations.

a) $H_2 + Cl_2 \rightarrow$ _____

b) $Fe + Cl_2 \rightarrow$ _____

c) $Cl_2 + KBr \rightarrow$ _____

d) $N_2 + 3H_2 \rightarrow$ _____

e) $Mg + N_2 \rightarrow$ _____

3. Complete the table about Group 16 elements. [4]

Property	Oxygen	Sulfur
Physical state at room temperature		
Colour		
Common oxide / compound		
Allotropic forms		

4. Acid rain. [3]

Answer the questions.

a) State two causes of acid rain formation. [2]

b) Give one environmental effect of acid rain. [1]

5. Group 15 compounds: ammonia and ammonium salts. [3]

a) Write the chemical formula of ammonia: _____ [1]

b) Is ammonia acidic or basic in water? _____ [1]

c) Complete the reaction: $NH_4Cl(aq) + NaOH(aq) \rightarrow$ _____ + _____ + _____ [1]

6. Calculation. [3]

Hydrogen chloride is formed from hydrogen and chlorine:

$H_2 + Cl_2 \rightarrow 2HCl$

If 1.0 g of hydrogen reacts completely with excess chlorine, calculate the theoretical mass of HCl produced.

Ar: H = 1, Cl = 35.5

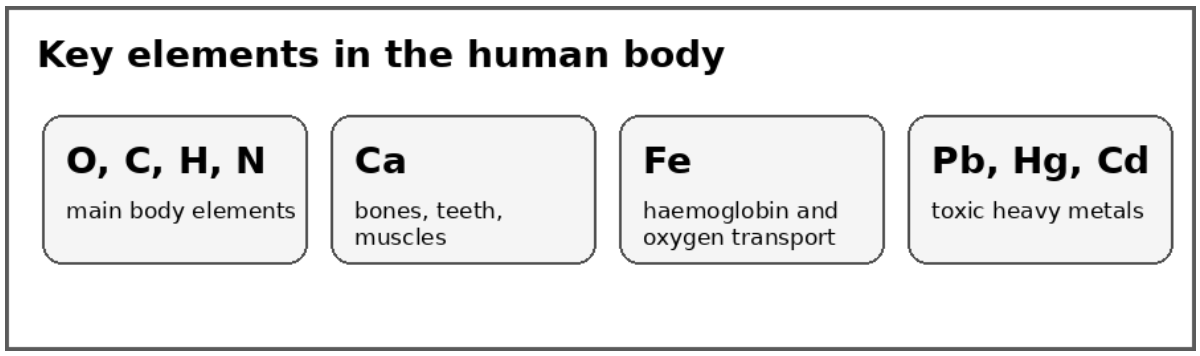
Mark Scheme

Assessment Criterion	Task №	Descriptor	Marks	Notes
Completes statements about trends in Group 17 and Group 15 elements	1	States that melting and boiling points increase down Group 17	1	increase
	1	States that oxidizing ability decreases down Group 17	1	decreases

	1	Identifies Group 15 elements as pnictogens	1	pnictogens
Writes balanced equations for reactions involving chlorine and nitrogen	2	Writes $H_2 + Cl_2 \rightarrow 2HCl$	1	balanced
	2	Writes $2Fe + 3Cl_2 \rightarrow 2FeCl_3$	1	accept $FeCl_3$
	2	Writes $Cl_2 + 2KBr \rightarrow 2KCl + Br_2$	1	displacement
	2	Writes $N_2 + 3H_2 \rightarrow 2NH_3$	1	Haber reaction
	2	Writes $3Mg + N_2 \rightarrow Mg_3N_2$	1	magnesium nitride
Compares properties of Group 16 elements	3	Correctly states physical states of oxygen and sulfur	1	gas; solid
	3	Correctly states colours of oxygen and sulfur	1	colourless; yellow
	3	Gives suitable common oxide/compound for each element	1	e.g. H_2O, SO_2
	3	Gives suitable allotropic forms	1	e.g. O_2/O_3; rhombic/monoclinic sulfur
Explains acid rain formation and effects	4	States two causes of acid rain formation	2	SO_2, NOx from combustion, industry or transport
	4	Gives one environmental effect of acid rain	1	plants, soil, water, buildings
Identifies properties and reactions of ammonia	5	Writes formula NH_3	1	NH_3
	5	States ammonia is basic in water	1	basic/alkaline
	5	Completes $NH_4Cl + NaOH$ reaction	1	$NaCl + NH_3 + H_2O$
Solves stoichiometric calculation using a balanced equation	6	Calculates moles of H_2 correctly	1	1.0 g / 2 g mol^{-1} = 0.5 mol
	6	Uses correct mole ratio H_2:HCl = 1:2	1	0.5 mol H_2 gives 1.0 mol HCl
	6	Calculates theoretical mass of HCl	1	36.5 g
Total			**21**	

Post-test for General secondary school
Unit: “Chemical Elements in the Human Body”

Chemistry: Grade 9
Student full name: _____
Grade: _____ Date: _____
Time allowed: 25 minutes Total: 21 marks



Learning objectives

• Name chemical elements present in the human body and explain their importance.
• Explain the role of calcium and iron in the human body.
• Identify sources of environmental pollution by heavy metals.
• Explain the effects of heavy metals on living organisms.

Assessment criteria

• Identifies elements found in the human body and describes their functions.
• Describes the biological importance of calcium and iron.
• Classifies elements as macroelements, microelements or toxic heavy metals.
• Explains pathways and effects of heavy metals in organisms.
• Analyses a short environmental case study.
Thinking skills level: Knowledge and understanding; Application

Tasks

1. Fill in the gaps. [3]

a) The most abundant elements in the human body include oxygen, carbon, hydrogen and _____.

b) Calcium is important for bones, teeth and _____ contraction.

c) Iron is a part of haemoglobin and helps transport _____ in the blood.

2. Complete the table about elements in the human body. [4]

Element	Main role in the body	Type of element
Calcium (Ca)		macroelement
Iron (Fe)		microelement
Potassium (K)		macroelement
Iodine (I)		microelement

3. Calcium and iron. Answer the questions. [4]

a) Give two functions of calcium in the human body. [2]
b) Explain why iron deficiency can cause anaemia. [2]

4. Heavy metal pollution. [3]

a) Name two sources of environmental pollution by heavy metals. [2]

b) Name one way heavy metals can enter the human or animal body. [1]

5. Explain the effects of heavy metals on living organisms. [3]

Write three possible harmful effects of heavy metals on humans, animals or plants.

6. Case study. [4]

Near industrial areas, soil can contain increased amounts of heavy metals. In one example, the zinc concentration in soil was 7.4 times higher than the allowed level.

a) Explain why this situation is dangerous for plants and animals. [2]

b) Suggest two measures to reduce heavy metal pollution. [2]

Mark Scheme

Assessment Criterion	Task №	Descriptor	Marks	Notes
Completes statements about elements in the human body	1	Identifies nitrogen as one of the main elements	1	nitrogen / N
	1	States that calcium is important for muscle contraction	1	accept muscles
	1	States that iron helps transport oxygen	1	oxygen / O_2
Describes roles and types of elements	2	Gives a correct role of calcium	1	bones, teeth, clotting, muscles
	2	Gives a correct role of iron	1	haemoglobin, oxygen transport
	2	Gives a correct role of potassium	1	nerve impulses, muscles, water balance
	2	Gives a correct role of iodine	1	thyroid hormones
Explains the role of calcium and iron	3	Gives two correct functions of calcium	2	1 mark each
	3	Explains iron deficiency and anaemia correctly	2	low haemoglobin / less oxygen transport
Identifies sources and pathways of heavy metals	4	Names two sources of heavy metal pollution	2	industry, mining, transport, batteries, waste
	4	Names one pathway into organisms	1	food, water, air, soil
Explains effects of heavy metals	5	States three harmful effects on organisms	3	1 mark each
Analyses environmental case study	6	Explains danger of increased zinc/heavy metals	2	toxicity, bioaccumulation, reduced growth
	6	Suggests two measures to reduce pollution	2	treatment, monitoring, recycling, filters
Total			**21**	

Pre-test for Lyceum

“Qualitative Analysis of Inorganic Compounds”

Chemistry: Grade 9

Student full name: _____
Grade: _____ Date: _____
Time allowed: 25 minutes **Total: 21 marks**

Learning objectives

• Identify common cations and anions using qualitative tests.
• Describe the formation of precipitates in reactions of ions.
• Write word and balanced chemical equations for qualitative reactions.
• Apply stoichiometric calculations to determine the limiting reagent.

Assessment criteria

• Completes statements about qualitative tests correctly.
• Chooses correct answers about ions, precipitates and flame tests.
• Describes cation tests using sodium hydroxide solution.
• Identifies anions and gases using appropriate reagents.
• Explains key terminology related to qualitative analysis.
• Solves a limiting-reagent problem using a balanced equation.

Thinking skills level: Knowledge and understanding; Application

Tasks

1. Fill in the gaps. [3]

a) When silver nitrate reacts with sodium chloride, a _____ precipitate of silver chloride is formed.

b) The equation for the reaction of a carbonate with an acid is:

$K_2CO_3(aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + H_2O(l) +$ _____(g)

c) In qualitative analysis, a precipitate is an _____ solid formed in a solution.

2. Multiple choice questions. Choose one correct answer. [5]

1) Which ion produces a blue precipitate when reacted with hydroxide ions (OH^-)?
A) Fe^{2+} B) Cu^{2+} C) Zn^{2+} D) Fe^{3+}

2) Which anion produces a white precipitate with Ba^{2+} ions?
A) SO_4^{2-} B) NO_3^- C) Cl^- D) CO_3^{2-}

3) What gas is produced when hydrochloric acid reacts with a carbonate compound?
A) Oxygen B) Hydrogen C) Carbon dioxide D) Nitrogen

4) The red colour in fireworks is caused by which ion?
A) Na^+ B) Sr^{2+} C) Cu^{2+} D) Ba^{2+}

5) An unknown salt solution produces a reddish-brown precipitate with NaOH. Which cation is most likely present?
A) Fe^{2+} B) Fe^{3+} C) Cu^{2+} D) Zn^{2+}

3. Complete the table for cation tests with sodium hydroxide solution. [4]

Cation	Observation with NaOH(aq)	Conclusion
Cu^{2+}	_____	Copper(II) ion is present
Fe^{2+}		Iron(II) ion is present
Fe^{3+}	_____	Iron(III) ion is present
Zn^{2+}		Zinc ion is present

4. Identify the substances or products in the following qualitative tests. [3]

a) A solution gives a white precipitate with acidified $BaCl_2$. The anion is _____.

b) A carbonate reacts with dilute acid and the gas turns limewater milky. The gas is _____.

c) A chloride solution reacts with $AgNO_3$ and forms a white precipitate. Write the ionic equation:

_____

5. Define the following terms. [3]

qualitative analysis:

precipitate:

recrystallization:

6. Calculate the limiting-reagent problem. [3]

Aluminium reacts with chlorine according to the equation:

$2Al + 3Cl_2 \rightarrow 2AlCl_3$

Given: 10.0 g Al and 35.0 g Cl_2.

a) Determine the limiting reagent.

_____

b) Calculate the maximum mass of $AlCl_3$ that can be produced. Show your working.

_____

Mark Scheme

Assessment Criterion	Task №	Descriptor	Marks	Notes
Completes statements about qualitative tests correctly	1	Identifies white precipitate of AgCl	1	white
	1	Identifies CO_2 as the gas from carbonate and acid	1	carbon dioxide
	1	Defines a precipitate as an insoluble solid	1	accept insoluble
Chooses correct answers about ions, precipitates and flame tests	2	Chooses correct answer for Cu^{2+} with OH^-	1	B
	2	Chooses correct answer for sulfate with Ba^{2+}	1	A
	2	Chooses correct gas from carbonate and acid	1	C
	2	Chooses Sr^{2+} for red flame colour	1	B
	2	Chooses Fe^{3+} for reddish-brown precipitate	1	B
Describes cation tests using sodium hydroxide solution	3	States blue precipitate for Cu^{2+}	1	$Cu(OH)_2$
	3	States green precipitate for Fe^{2+}	1	$Fe(OH)_2$

	3	States reddish-brown precipitate for Fe^{3+}	1	$Fe(OH)_3$
	3	States white precipitate for Zn^{2+}, soluble in excess NaOH	1	accept white ppt
Identifies anions and gases using appropriate reagents	4	Identifies sulfate ion from $BaCl_2$ test	1	SO_4^{2-}
	4	Identifies carbon dioxide from limewater test	1	CO_2
	4	Writes $Ag^+ + Cl^- \rightarrow AgCl$ correctly	1	state symbols optional
Explains key terminology related to qualitative analysis	5	Defines qualitative analysis	1	identification of substances/ions
	5	Defines precipitate	1	insoluble solid formed
	5	Defines recrystallization	1	purification by dissolving and crystallizing
Solves a limiting-reagent problem using a balanced equation	6	Calculates/identifies chlorine as the limiting reagent	1	Cl_2
	6	Uses correct mole ratio to find moles of $AlCl_3$	1	0.329 mol $AlCl_3$
	6	Calculates maximum mass of $AlCl_3$	1	43.9 g approximately
Total			**21**	

Post-test for Lyceum

Unit: "The Rate of Chemical Reactions"
Chemistry: Grade 9

Student full name: _____
Grade: _____ Date: _____
Time allowed: 25 minutes Total: 21 marks

Learning Objectives

• Explain factors affecting the rate of chemical reactions.
• Describe collision theory.
• Interpret experimental data related to reaction rates.
• Predict the effect of catalysts, temperature and concentration.
• Calculate reaction rates from experimental results.

Assessment Criteria

• Identifies factors affecting reaction rate.
• Explains collision theory.
• Interprets tables and graphs.
• Performs reaction rate calculations.

Thinking Skills Level: Knowledge and Understanding; Application

Tasks

1. Fill in the gaps. [3]

The speed of a chemical reaction is called the reaction _____.
A substance that increases reaction rate without being consumed is a _____.
Increasing temperature usually _____ the rate of reaction.

2. Multiple choice questions. Choose one correct answer. [5]

Which factor does NOT affect reaction rate?
A) Density B) Temperature C) Concentration D) Surface area

Which condition gives the fastest reaction?
A) Low temperature B) High temperature C) Large crystals D) Dilute solution

A catalyst:
A) Slows reaction B) Stops reaction C) Increases reaction rate D) Is consumed

Which reacts fastest?
A) Powdered zinc B) Zinc block C) Large zinc piece D) Zinc sheet

Increasing concentration usually:
A) Decreases rate B) Increases rate C) Stops reaction D) No effect

3. Complete the table. [4]

Factor	Effect on Rate	Reason
Temperature		
Concentration		
Surface Area		
Catalyst		

4. Short-answer questions. [3]

a) Explain why powdered solids react faster than large lumps. (1)
b) Explain the effect of temperature on particle collisions. (2)

5. Graph interpretation. [3]

Describe how the rate of reaction changes as temperature increases. Explain your answer.

6. Calculation. [3]

A reaction produced 60 cm^3 of gas in 30 seconds. Calculate the average rate of reaction in cm^3/s. Show your working.

Mark Scheme

Assessment Criterion	Task №	Descriptor	Marks	Notes
Identifies reaction rate concepts	1	Completes each statement correctly	3	1 mark each
Chooses correct answers	2	Five correct MCQ answers	5	1 mark each
Explains factors affecting rate	3	Completes table correctly	4	1 mark each row
Explains collision theory	4	Answers short questions	3	
Interprets reaction trends	5	Explains graph trend correctly	3	
Calculates reaction rate	6	Correct calculation and unit	3	

Total: 21 marks

Pre-test for International School
Unit: “Group 15 Elements and Their Compounds”

Student full name: _____

Grade: _____

Time allowed: 25 minutes Total: 21 marks

Tasks

1. Complete the statements about Group 15 elements. [3 marks]

a) The elements of Group 15 are called _____.

b) They have _____ valence electrons in the outer shell.

c) Down the group, metallic character _____.

2. Complete the table about nitrogen. [4 marks]

Property	Answer	Marks
Chemical symbol		1
Atomic number		1
Electron configuration		1
Number of protons		1

3. Complete and balance the chemical equations. [4 marks]

a) $N_2 + H_2$ ->_____[1]

b) $Mg + N_2$ ->_____[1]

c) Li + N2 ->_____[1]

d) $N_2 + O_2$ ->_____[1]

4. Answer the questions about ammonia. [4 marks]

a) Write the chemical formula of ammonia: _____[1]

b) Is ammonia acidic or basic? _____[1]

c) What colour does ammonia turn moist red litmus paper? _____ [1]
d) Write the Haber process reaction: _____[1]

5. Complete and balance the reactions of ammonium salts with alkalis. [3 marks]

a) $NH_4Cl(aq) + NaOH(aq) \rightarrow$ [1]
b) $(NH_4)_2SO_4(aq) + KOH(aq) \rightarrow$ [2]

6. Nitric acid, nitrates and fertilizers. [3 marks]

a) Write the chemical formula of nitric acid: [1]
b) Name one nitrate salt: _____[1]
c) Write the three main macronutrients in fertilizers: _____[1]

Mark Scheme

Assessment Criterion	Task №	Descriptor / Correct Answer	Marks	Notes
Identifies general features of Group 15 elements	1	Pnictogens - 1; five valence electrons - 1; metallic character increases down the group - 1	3	
Describes atomic structure of nitrogen	2	Chemical symbol: N	1	
		Atomic number: 7	1	
		Electron configuration: $1s^2\ 2s^2\ 2p^3$ or 2,5	1	
		Number of protons: 7	1	
Writes balanced reactions of nitrogen	3	$N_2 + 3H_2 \rightarrow 2NH_3$	1	
		$3Mg + N_2 \rightarrow Mg_3N_2$	1	
		$6Li + N_2 \rightarrow 2Li_3N$	1	
		$N_2 + O_2 \rightarrow 2NO$	1	High temperature is acceptable as a condition.
Describes properties and synthesis of ammonia	4	Formula: NH_3	1	
		Ammonia is basic	1	
		Turns moist red litmus paper blue	1	
		$N_2 + 3H_2 \rightleftharpoons 2NH_3$	1	Haber process; balanced equation accepted.
Completes reactions of ammonium salts with alkalis	5	$NH_4Cl + NaOH \rightarrow NH_3 + NaCl + H_2O$	1	
		$(NH_4)_2SO_4 + 2KOH \rightarrow 2NH_3 + K_2SO_4 + 2H_2O$	2	1 mark for products; 1 mark for balancing.
Identifies nitric acid, nitrates and fertilizer nutrients	6	Chemical formula of nitric acid: HNO_3	1	
		Any correct nitrate, e.g. KNO_3, $NaNO_3$, NH_4NO_3	1	
		Nitrogen, phosphorus and potassium / N, P, K	1	
Total			**21**	

Post-test for International School
Unit: "Group 17 and Group 16 Elements and Their Compounds"

Learning Objectives	9.2.1.8 Predict trends in the properties of halogens within the group. 9.2.1.9 Describe the chemical properties of chlorine: reactions with metals, hydrogen, and halides. 9.2.11.16 Describe the general properties of Group 16 elements. 9.4.2.1 Explain the causes of acid rain formation and its environmental impact. 9.2.3.3 Calculate the percentage yield of a reaction product compared with the theoretical yield. 9.2.1.10 Describe the differences in the reactions of dilute and concentrated nitric acid with metals and write the corresponding chemical equations.
Assessment Criteria	The learner: • predicts trends in the properties of halogens within the group; • describes the chemical properties of chlorine, including its reactions with metals, hydrogen, and halides; • describes the general properties of Group 16 elements; • explains the causes and environmental effects of acid rain; • calculates the percentage yield of a reaction product compared with the theoretical yield; • describes the differences in the reactions of dilute and concentrated nitric acid with metals and writes balanced chemical equations.
Thinking Skills Level	Knowledge and Understanding; Application
Time Allowed	25 minutes

Tasks

1. Complete the statements using the appropriate words.

In the series from fluorine to iodine, the density of the simple substances....., their colour becomes....., and their melting and boiling points..... As the atomic number increases down the group, the atomic radius .... the oxidizing ability....., and therefore the reducing ability.....[3]

2. Chlorine is a strong oxidizing agent. Write the equations of the possible reactions of chlorine with the following substances:

H_2, Fe, P, KF, KBr

_____[5]

3. The Group VIA elements are called chalcogens. Complete the table and describe how the properties of chalcogen atoms change as the nuclear charge increases.

Property	**Oxygen**	**Sulfur**
Physical state under standard conditions		
Colour		
Crystal structure		
Electronegativity		
Metallic character		
Stability of hydrogen compounds		
Allotropic forms		

[3]

4. Acid rain has become one of the major environmental problems today.



1) State three causes of acid rain formation.

_____[3]

2) Give three examples of the effects of acid rain on the environment.

_____[3]

5. By synthesizing hydrogen chloride from 1 g of hydrogen gas and chlorine, 32 g of hydrogen chloride gas was obtained. Determine the percentage yield of the product compared with the theoretical yield.

A) 7,63%

B)67,84%

C)13,85%

D) 87,67%

E)36,77% [2]

6. Describe the reaction of copper with concentrated sulfuric acid and write the balanced chemical equation.

$Cu + H_2SO_4$ (conc.) → _____[2]

Mark Scheme

Assessment Criterion	Task №	Descriptor	Marks
		The learner:	
Predicts trends in the properties of halogens within the group	1	Correctly completes the statements	3
Describes the chemical properties of chlorine	2	Writes the equation for the reaction with hydrogen	1
		Writes the equation for the reaction with iron	1
		Writes the equation for the reaction with phosphorus	1
		States that chlorine does not react with potassium fluoride	1
		Writes the equation for the reaction with potassium bromide	1
Describes the general properties of Group 16 elements	3	Identifies physical state, colour, and crystal structure	1
		Describes changes in electronegativity and metallic character	1
		Describes changes in compound stability and allotropy	1
Explains the causes and environmental effects of acid rain	4	States three causes of acid rain formation	3
		Gives three environmental effects of acid rain	3
Calculates percentage yield	5	Correctly determines percentage yield	2
Describes the reaction of copper with concentrated sulfuric acid and writes the balanced chemical equation	6	Writes the balanced equation for the reaction of copper with concentrated sulfuric acid	1
		Identifies sulfur dioxide as the gaseous product and/or explains the oxidizing property of concentrated sulfuric acid	1
Барлығы			**21**

Appendix 3

Table A3.1. Student Reflective Feedback Survey Questions.

1. How well did you understand the lessons with STEM elements?	2. Which part of the STEM-based lessons did you like the most?	3. What difficulties did you face during these lessons?	4. How did these lessons affect your interest in chemistry?
a. Understood very well	a. Group work	a. Difficult to understand tasks	a. Increased a lot
b. Understood well	b. Problem-solving tasks	b. Not enough time	b. Increased
c. Understood at an average level	c. Individual work	c. Difficult to connect chemistry with other subjects	c. No change
d. It was difficult	d. Connection with other subjects (mathematics, technology, etc.)	d. Difficult to work in a group	d. Did not change at all
e. It was very difficult		e. No difficulties	e. Decreased

Table A3.2. Mean Expert Scores for Each Survey Question by Evaluation Criterion.

Evaluation Criterion	**Q.1**	**Q.2**	**Q.3**	**Q.4**
Clarity	3.00	2.75	2.75	2.50
Relevance	2.75	2.25	3.00	2.75
Content coverage	3.00	2.75	2.75	3.00
Comprehensibility	3.00	3.00	3.00	3.00
Ethics	3.00	3.00	3.00	3.00
Usefulness	2.75	2.75	3.00	3.00
Mean	**2.92**	**2.75**	**2.92**	**2.88**

Appendix 4

Table A4.1. Calculation of the cost and mass fraction of chemical elements in the human body

Element	Mass fraction of the element in the body, %	Amount of the element in the human body, kg (X)	Mass of the element in my body, kg	Price of one element, tg	Amount of the element needed for the human body, tg
Oxygen	61	61/100*X		915	
Carbon	23	23/100*X		4512	
Hydrogen	10	10/100*X		44775	
Nitrogen	2.5	2.5/100*X		427	
Calcium	1.4	1.4/100*X		38448	
Phosphorus	1.1	1.1/100*X		5607	
Potassium	0.2	0.2/100*X		210930	
Sulfur	0.2	0.2/100*X		2509	
Sodium	0.14	0.14/100*X		22000	
Chlorine	0.13	0.13/100*X		52927	
Magnesium	0.03	0.03/100*X		9318	
Iron	0.006	0.006/100*X		13216	
Total price:					

Figure A4.1. Example of collaborative learning in STEM-integrated chemistry instruction (Mini-project on chemical elements in the human body)



Figure A4.2. Design and Construction of a Simple Water Filter Using Common Materials

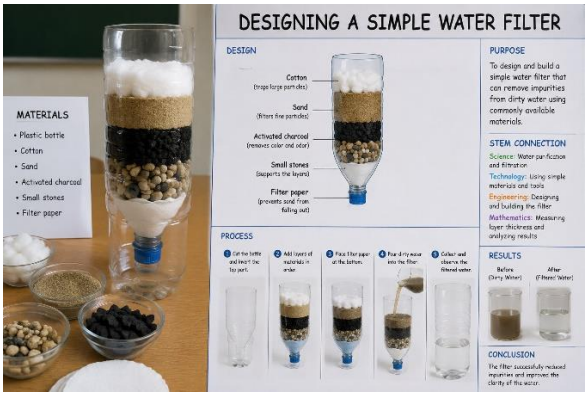


Figure A4.3. Java-Based Virtual Laboratory Simulation for Investigating Factors Affecting Reaction Rates.

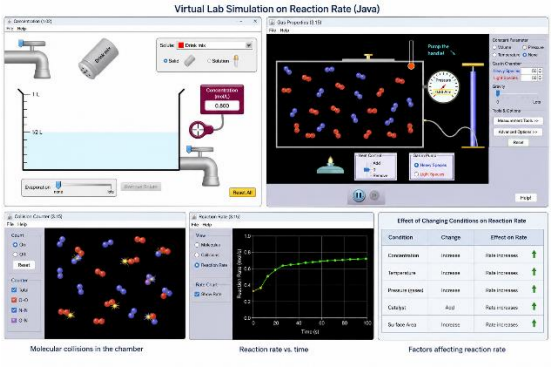


Figure A4.4. Laboratory Experiments on Factors Affecting Reaction Rates

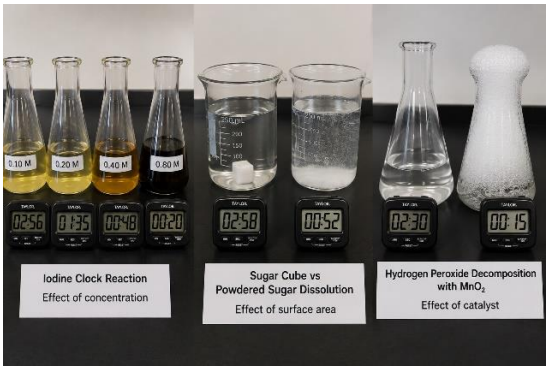


Figure A4.5. Anti-Browning Apple Project

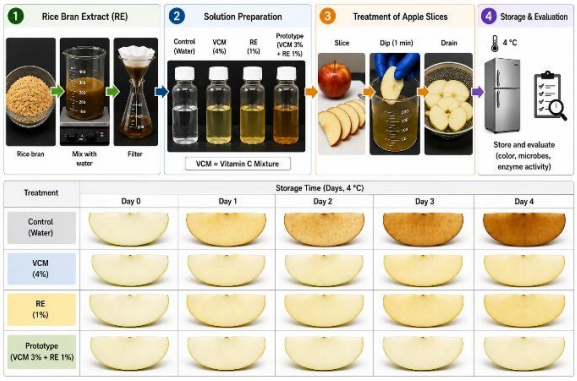


Figure A4.6. Demonstration of Sulfur Allotropy through Plastic Sulfur Formation

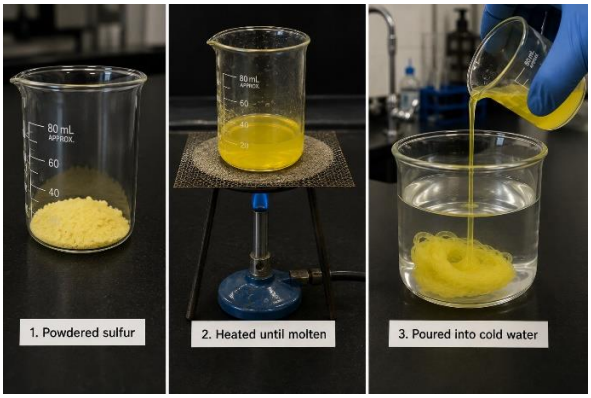


Figure A4.7. Laboratory Electrolysis of Sodium Chloride and Industrial Chlorine Production

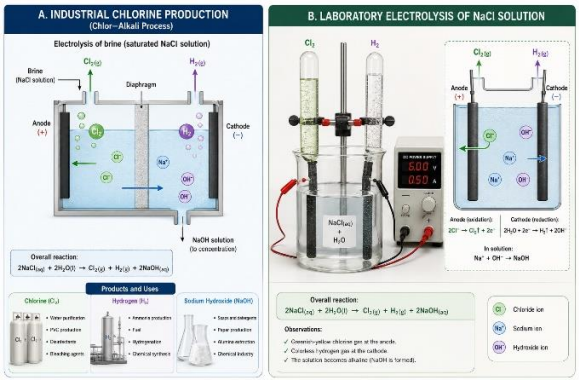


Figure A4.8. Laboratory Investigation of Chemical Reactions Involving HCl, Zn, and NaOH

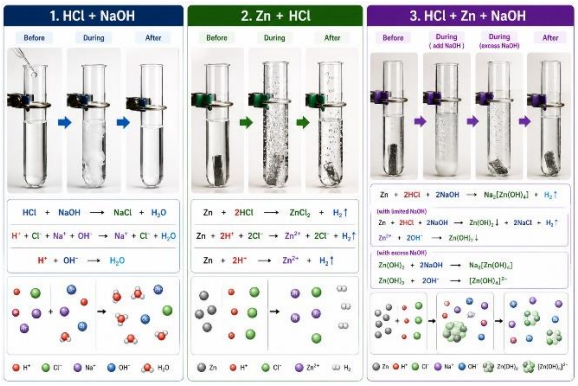


Table A5.1. Homogeneity of Variances Test (Levene's Test) for ANCOVA – General Secondary School

Homogeneity of Variances Test (Levene's)			
F	df1	df2	p
2.05	1	48	.159

Table A5.2. Normality Test (Shapiro–Wilk) for ANCOVA – General Secondary School

Normality Test (Shapiro-Wilk)	
Statistic	p
0.955	.054

Figure A4.1. Normality Check (Q–Q Plot) for ANCOVA – General Secondary School

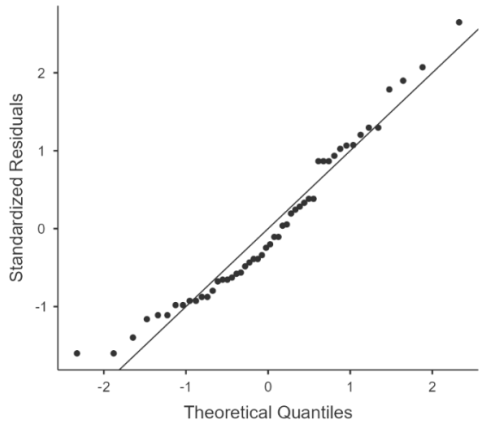


Table A5.3. Homogeneity of Variances Test (Levene's Test) for ANCOVA – Lyceum

Homogeneity of Variances Test (Levene's)			
F	df1	df2	p
0.657	1	35	.423

Table A5.4. Normality Test (Shapiro–Wilk) for ANCOVA – Lyceum

Normality Test (Shapiro-Wilk)	
Statistic	p
0.965	.282

Figure 5.2. Normality Check (Q–Q Plot) for ANCOVA – Lyceum

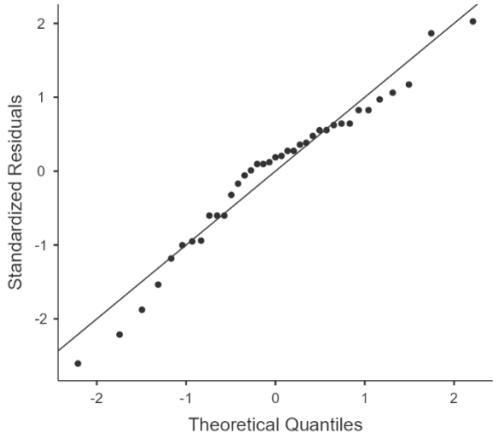


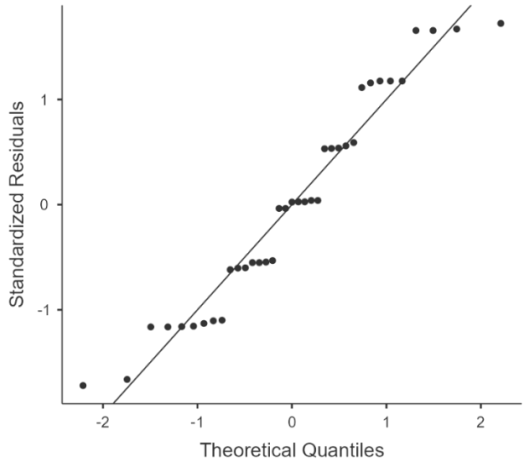
Table A5.5. Homogeneity of Variances Test (Levene's Test) for ANCOVA – International School

Homogeneity of Variances Test (Levene's)			
F	df1	df2	p
0.864	1	35	.359

Table A5.6. Normality Test (Shapiro–Wilk) for ANCOVA – International School

Normality Test (Shapiro-Wilk)	
Statistic	p
0.945	.066

Figure A5.3. Normality Check (Q–Q Plot) for ANCOVA – International School



Appendix 6

Table A6.1. Distribution of STEM instructional methods and activities across the analyzed studies

Authors	Hands-on laboratory activities	Problem-solving tasks	Inquiry activities	Engineering design tasks	Project work / mini-projects	Modeling (physical and digital models)	Use of digital technologies	Collaborative learning	Interdisciplinary approach	Data collection and analysis	Student-centered learning activities	Presentation and communication activities	Reflection and discussion
Bunyamin, M. A. H., Talib, C. A., Ahmad, N. J., Ibrahim, N. H., & Surif, J., 2020.	+	+	+	+		+		+	+	+	+	+	+
Özkul, H., & Özden, M., 2020.	+	+	+	+	+		+	+	+	+	+	+	+
Shukri, A. A. M., Ahmad, C. N. C., & Daud, N., 2020.		+	+	+	+	+		+	+	+	+	+	+
Wang, H.-H., Charoenmuang, M., Knobloch, N. A., & Tormoehlen, R. L., 2020.	+	+	+	+	+			+	+	+	+		+
Yang, D., & Baldwin, S. J., 2020.	+	+	+	+	+	+	+	+	+	+	+		+
Awad, N., 2021.	+	+			+		+	+	+		+	+	
Dare, E. A., Keratithamkul, K., Hiwatig, B. M., & Li, F., 2021.	+	+	+	+	+			+	+	+	+		+
De Meester, J., De Cock, M., Langie, G., & Dehaene, W., 2021.	+	+	+	+	+			+	+	+	+		+
Isdianti, M.F., Nasrudin, H., & Erman, E., 2021.	+	+	+	+	+	+	+	+	+	+	+	+	+
Nurmaliah, C., Azmi, T. N., Safrida, Khairil, & Artika, W., 2021.	+	+		+	+			+	+		+		

Authors	Hands-on laboratory activities	Problem-solving tasks	Inquiry activities	Engineering design tasks	Project work / mini-projects	Modeling (physical and digital models)	Use of digital technologies	Collaborative learning	Interdisciplinary approach	Data collection and analysis	Student-centered learning activities	Presentation and communication activities	Reflection and discussion
Hamad, S.; Tairab, H.; Wardat, Y. et al., 2022.	+	+	+	+	+			+	+	+	+		+
Han, J., Kelley, T., & Knowles, J. G., 2022.	+		+	+		+	+	+	+	+	+		
Hasibuan, M. P.; Sari, R. P.; Syahputra, R. A.; Nahadi., 2022.		+	+	+	+		+	+	+	+	+	+	+
McLure, F.; Tang, K.-S.; Williams, P. J., 2022.		+	+	+	+			+	+		+		
Wilkerson, J. R.; Schorr, M. T.; Peltz, B. C., 2022.		+	+	+	+			+	+	+	+	+	+
Dibyantini, R.E., Amdayani, S., Siregar, M.I., & Syafriani, D., 2023.		+			+			+	+	+	+		
Gusman, T.A., Novitasari, & Yulina, I.K., 2023.	+	+	+	+	+			+	+	+	+		+
Media Roza, Lufri, Asrizal., 2023.		+	+					+	+		+	+	
Sarıoğlan, A.B., & Şentürk Özkaya, Ö., 2023.	+	+	+	+	+	+	+	+	+	+	+	+	+
Sulaiman, F., Rosales Jr., J.J., & Lee, J.K., 2023.	+	+	+	+	+			+	+	+	+	+	+
AlAli, R., 2024.	+	+		+	+			+	+	+	+		
Fitriyana, N.; Wiyarsi, A.; Pratomo, H.; Marfuatun, M., 2024.	+	+	+	+			+		+	+			

Authors	Hands-on laboratory activities	Problem-solving tasks	Inquiry activities	Engineering design tasks	Project work / mini-projects	Modeling (physical and digital models)	Use of digital technologies	Collaborative learning	Interdisciplinary approach	Data collection and analysis	Student-centered learning activities	Presentation and communication activities	Reflection and discussion
Ismail, M. H.; Fadzil, H. M.; Mat Salleh, M. F.; Saat, R. M.; Kurniawan, C.; Hariyono, E., 2024.	+	+	+		+			+	+			+	+
Ningtyas, P. K.; Widarti, H. R.; Parlan, P.; Rahayu, S.; Dasna, I. W., 2024.		+	+	+	+		+	+	+		+		+
Simanjuntak, Y. I. W.; Purwaningsih, D., 2024.	+	+	+	+		+	+	+	+	+	+	+	+
Haleda, P.; Isa, I.; Munandar, H.; Bialangi, N.; Tangio, J. S.; Thayban; Kurniawati, E., 2025.		+	+	+	+			+	+		+	+	+
Nipyrakis, A.; Stavrou, D.; Avraamidou, L., 2025.	+	+	+	+	+	+	+	+	+	+	+	+	+
Setiawan, V. R.; Situmorang, M.; Silaban, R., 2025.	+	+	+	+	+		+	+	+	+	+	+	+
Shagrayeva, B.; Shertayeva, N.; Zhorabekova, A.; Baymakhanova, G.; Toktamys, N., 2025.	+	+	+	+	+	+	+	+	+	+	+	+	+
Toktamys, N.B., Shagrayeva, B.B., Shertayeva, N.T., & Bitemirova, A.E., 2025.	+	+		+	+			+	+	+	+	+	

Table A7.1. Descriptive Statistics for Pre-Test Scores – General Secondary School

Descriptives

	Group	pre test
N	Experimental	26
	Control	24
Mean	Experimental	11.1
	Control	11.9

Table A7.2. Descriptive Statistics for Post-Test Scores – General Secondary School

Descriptives

	Group	post test
N	Experimental	26
	Control	24
Mean	Experimental	14.5
	Control	13.4

Table A7.3. Descriptive Statistics for Pre-Test Scores – Lyceum

Descriptives

	Group	pre test
N	Experimental	18
	Control	19
Mean	Experimental	12.2
	Control	10.8

Table A7.4. Descriptive Statistics for Post-Test Scores – Lyceum

Descriptives

	Group	post test
N	Experimental	18
	Control	19
Mean	Experimental	15.2
	Control	12.5

Table A7.5. Descriptive Statistics for Pre-Test Scores – International School

Descriptives

	Group	pre test
N	Experimental	19
	Control	18
Mean	Experimental	10.5
	Control	10.7

Table A7.6. Descriptive Statistics for Post-Test Scores – International School

Descriptives

	Group	post test
N	Experimental	19
	Control	18
Mean	Experimental	13.5
	Control	11.8