Ministry of Education and Science of the Republic of Kazakhstan
SDU University
Faculty of Education and Humanities
Department of Pedagogy of Natural Sciences

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Creating the Integrative STEM Lesson Unit Plan for 10th Grade Students

MASTER’S DEGREE DISSERTATION

7M01502 - Chemistry

Kaskelen, 2025

Faculty of Education and Humanities
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CONTENTS

ABSTRACT

This master's thesis examines the creation and implementation of an integrative STEM method in the educational process based on 10th grades through the use of a Unit Plan/Curriculum. The main purpose of the master's thesis is to introduce and evaluate the effectiveness of STEM methodology as a methodology capable of being integrated in educational institutions in Kazakhstan. Additionally evaluate and comprehensively study the aspects of the methodology based on the work of other authors in the literature review section. The study contains traditional teaching methods such as the use of modern teaching technologies, the use of digital tools, and practical processes during the lesson. In order to understand how familiar students are with the concept of STEM, a survey was conducted among 179 students of Colleges in Almaty. Also, based on the students' responses, a methodological guideline for teachers on the implementation of STEM with an emphasis on chemistry was created and a comparative analysis of two groups was conducted, one of which was taught the STEM methodology (experimental group) based on the methodological guideline and the group that was trained according to the traditional system. At the beginning and end of the training, two groups were tested to compare changes in the results. The results of the test study showed a positive trend in the assimilation of material and memorization in the experimental group, which was trained using the STEM methodology, as well as higher motivation for lessons and full involvement of students. As a result, this work can serve as a practical guide for integrating STEM methodology into the learning process and subsequent improvement for teachers who want to change the teaching format and try new things in teaching, thereby increasing student engagement in the learning process. According to the hypothesis, the introduction of STEM methodology will cause high student engagement and improve the quality of education.

Keywords: *STEM approach, High school chemistry, Integrative Chemistry, Teaching plan*

АҢДАТПА

Бұл магистрлік диссертация 10-сыныптар негізінде оқу процесіне интеграциялық STEM әдісін/Curriculum бірлігін пайдалану арқылы құруды және енгізуді қарастырады. Магистрлік диссертацияның негізгі мақсаты- Қазақстанның білім беру мекемелері жағдайында интеграциялануға қабілетті әдістеме ретінде STEM әдістемесінің тиімділігін енгізу және бағалау. Әдебиеттерге шолу бөліміндегі басқа авторлардың жұмыстарына сүйене отырып, Әдістеменің аспектілерін қосымша бағалау және жан-жақты зерттеу. Зерттеуде заманауи оқыту технологияларын пайдалану, цифрлық құралдарды пайдалану, сабақ барысында практикалық процестер сияқты дәстүрлі оқыту әдістері бар. Оқушылардың STEM тұжырымдамасымен қаншалықты танысқанын түсіну үшін Алматы қаласы колледждерінің 179 оқушысы арасында сауалнама жүргізілді. Сондай-ақ студенттердің жауаптары негізінде химияға баса назар аудара отырып, STEM енгізу бойынша педагогтар үшін әдістемелік нұсқау жасалды және екі топқа салыстырмалы талдау жүргізілді, олардың бірі STEM әдістемесі (эксперименттік топ) негізінде оқытылды.әдістемелік нұсқау және дәстүрлі жүйе бойынша оқытылған топ. Оқудың басында және соңында нәтижелердегі өзгерістерді салыстыру үшін екі топтық тест өткізілді. Тесттерді зерттеу нәтижелері STEM әдістемесі бойынша оқыған эксперименттік топта материалды игеру мен есте сақтаудың оң тенденциясын, сондай-ақ сабаққа деген жоғары мотивацияны және оқушылардың толық қатысуын көрсетті. Қорытындылай келе, бұл жұмыс STEM әдістемесін оқыту процесіне интеграциялау және оқыту форматын өзгерткісі келетін және оқытудағы жаңалықты байқап көргісі келетін оқытушылар үшін кейіннен жақсарту бойынша практикалық нұсқаулық ретінде қызмет ете алады, осылайша оқушылардың оқу процесіне қатысуын арттырады. Гипотезаға сәйкес, STEM әдісін енгізу оқушылардың жоғары қатысуын тудырады және білім сапасын жақсартады.

Кілт сөздер: *STEM тәсілі, орта мектептегі химия, интегративті химия, оқу жоспары*

АННОТАЦИЯ

Данная магистерская диссертация рассматривает создание и внедрение в учебный процесс на базе 10-х классов интегративный STEM метод путем использования Юнит плана/Curriculum. Основная цель магистерской диссертации – внедрить и оценить эффективность методики STEM как методика способная быть интегрированной в условиях образовательных учреждений Казахстана. Дополнительно оценить и всесторонне изучить аспекты методики опираясь на работы других авторов в разделе обзор литературы. Исследование содержит в себе традиционные методы обучения, такие как использование современных технологий преподавания, использование цифровых инструментов, практические процессы во время урока. Для того чтобы понять насколько ученики ознакомлены с концепцией STEM, был проведен опрос среди 179 учеников Колледжей города Алматы. Также на основе ответов студентов было создано методическое указание для педагогов по внедрению STEM с упором на химию и проведен сравнительный анализ двух групп, одной из которых преподавалась методика STEM (экспериментальная группа) основываясь на методическое указание и группа которая обучалась по традиционной системе. В начале и конце обучения проводился тест двух групп для сравнения изменений в результатах. Результаты исследования тестов показали положительную тенденцию в усвоении материала и запоминания в экспериментальной группе, которая как раз-таки обучалась по методике STEM, а также более высокую мотивацию к урокам и полную вовлеченность учащихся. По итогам, данная работа может послужить как практическое руководство по интегрированию методики STEM в процесс обучения и последующего улучшения для преподавателей желающих изменить формат преподавания и попробовать новизну в преподавании тем самым повысив вовлечение учащихся в процесс обучения. Согласно гипотезе, внедрение методики STEM вызовет высокую вовлеченность учеников и улучшит качество образования.

Ключевые слова: *STEM-подход, химия в старших классах, Интегративная химия, Учебный план*

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANCOVA – Analysis of Covariance
ANOVA – Analysis of Variance
CIS – Cooperative Instructional Strategy
CPT – Chemistry Performance Test
DNA – Deoxyribonucleic Acid
ERIC – Education Resources Information Center
HSCT – High School Chemistry Teachers
ICT – Information and Computer Technologies
IMT – Integrative-Modular Teaching
MANOVA – Multivariate Analysis of Variance
MGMP – Musyawarah Guru Mata Pelajaran (a teacher subject forum in Indonesia)
NSF – National Science Foundation
PC-STEM – Problem-Centered STEM
PLTW – Project Lead The Way
POGIL – Process Oriented Guided Inquiry Learning
SDU – Suleyman Demirel University
SSRN – Social Science Research Network
STEAM – Science, Technology, Engineering, Arts, and Mathematics
STEM – Science, Technology, Engineering, and Mathematics
TPACK – Technological Pedagogical Content Knowledge
VSCT – Vocational School Chemistry Teachers

LIST OF APPENDICES

INTRODUCTION

“You need to learn by doing something; for although you think you know it, you don’t have confidence until you try,” said Sophocles, emphasizing the vital link between action and understanding. Aristotle similarly observed, “What we have to learn, we learn by doing.” Galileo Galilei argued that one cannot directly teach knowledge but only assist others in discovering it within themselves, and John Dewey reinforced this idea by asserting that “no thought, no idea can be transmitted as an idea from one person to another.” Collectively, these thinkers highlight an enduring truth: deep, lasting learning arises not from passive reception but from active engagement and practice. Despite the achievements of these intellectual giants, modern education systems, especially in secondary schools, often do not facilitate such engagement. In many classrooms, traditional methods based on lectures and memorization of the more theoretical part of textbooks are more prevalent, when students act as passive recipients of information, while teachers remain the only active participants and only the teacher contacts the audience, not mutually. As Felder and Brent (2024) point out, this outdated model often fails to stimulate curiosity or foster meaningful understanding, becoming an obstacle to lifelong learning for many students. The demands of the 21st century require fundamental changes in terms of approaches to education. Students should develop skills that will prepare them not only to take standardized tests, but also to solve complex real-world problems. Based on the statements of Rahmavati et al. (2019), modern education should strive to develop skills that help students solve both current and future tasks, in a word, to be able to think ahead, for the future. As we live in an age of rapid technological advancement, a growing climate crisis, and more globally-connected individuals, it is not sufficient to teach knowledge in an academic isolation. Students need to synthesize and utilize knowledge across fields to create innovative and functional solutions. It is the very purpose of STEM education (science, technology, engineering, and mathematics), known in the early 2000s in the United States by the National Science Foundation (NSF) through its initiatives and initiatives. STEM is more than simply a curriculum trend. It is a transformational educational philosophy that takes a multidisciplinary perspective, reflecting the complexities of existing challenges in our world, and allowing the student to be more interested in learning something new. STEM encourages students to observe, ask questions, experiment, design, calculate, and solve, thereby developing critical thinking, collaboration, and innovation skills. This work is based on the development of an integrative STEM lesson plan specifically designed for 10th grade students and has an hypothesis “An integrative STEM approach to chemistry teaching promotes a higher level of academic achievement and student engagement compared to traditional teaching methods, through interdisciplinarity, practical focus and increased motivation”. This learning phase is crucial because it marks a transitional period where students move from learning foundational concepts to more abstract, interconnected ideas. And just the same, the most responsible person in this action (teaching methods) is the teacher. After all, it is the teacher who determines how and what students will study based on his personal experience, any instructions. Given this critical period in development, the aim of this study is to create a modular plan that transcends traditional subject boundaries. Instead of presenting STEM subjects as isolated areas, this integrated model aims to identify their interrelationships and application possibilities in solving real-world problems, which is able to mentor teachers and give them some ideas in integrating STEM methodology. STEM education is also closely linked to the principles of the constructivist theory of learning, which states that knowledge is actively accumulated by students through meaningful experiences and social interaction. This theoretical framework defines the structure and philosophy of the learning unit, facilitating hands-on learning, project-based learning, and collaborative research. According to Kennedy and Odell (2014), STEM education should begin with scientific research-asking questions and seeking evidence-before moving on to engineering design processes to solve real-world problems. This integrative sequence reflects how professionals solve problems outside of the classroom, providing students with a more authentic learning experience.

Significance of the study: This study comes at a moment when rethinking how we teach isn’t just important-it’s necessary. Around the world, education systems are shifting, trying to keep up with a world that’s changing faster than ever. Technology, global challenges, and the need for flexible, creative thinking have made one thing clear: students need more than just knowledge-they need to know how to use it. STEM education is one of the ways schools are trying to meet that need, and chemistry, which sits at the crossroads of science and real-world application, plays a huge role in that process. But in Kazakhstan, STEM hasn’t fully found its way into everyday chemistry lessons. Most teachers understand how important it is, but many simply aren’t equipped to bring it into their classrooms. There’s a gap between what we hope for in our education system and what’s actually happening. Teachers often lack resources, experience with cross-subject teaching, or access to materials that match both the curriculum and STEM principles. As a result, students miss out on chances to explore, create, and connect their learning with the world around them.

That’s what makes this study relevant. It doesn’t just talk about the value of STEM-it offers something teachers can really use: a ready-to-go, flexible STEM unit plan built around the actual 10th-grade chemistry curriculum. It’s not some idealistic theory-it’s practical, classroom-tested, and made to work in real schools with real students.Even more importantly, this research listens to teachers. It looks at the problems they face, the things they need, and offers concrete tools that match those needs. It recognizes that improving education isn’t just about helping students-it’s also about giving teachers the support they deserve. In doing so, this study helps close the gap between policy and practice, between what’s written in national goals and what actually happens at the front of the classroom. The bigger picture? This research is about sparking real change. It shows that when STEM is done right in chemistry, students get more involved, understand more deeply, and perform better. Teachers feel more confident and better prepared. And in a country like Kazakhstan, which is actively working to modernize its education system, work like this helps set the foundation for a more relevant, practical, and future-ready way of teaching and learning.

Problem Statement: Despite growing global attention to STEM education, its practical integration into everyday teaching-especially in chemistry classrooms-remains limited in many parts of the world, including Kazakhstan. Schools often rely on traditional, theory-heavy methods that focus more on memorization than understanding. Students are expected to absorb abstract concepts without opportunities to explore, experiment, or connect what they’re learning to real-life situations. This passive approach can leave them disengaged, demotivated, and underprepared for the demands of the modern world. At the same time, many teachers are aware of the need for change. They see the potential of STEM-based approaches to make learning more dynamic, interdisciplinary, and hands-on. But they’re often left without the tools, training, or structured materials needed to turn that potential into practice. There’s a clear disconnect between the promise of STEM education and what’s actually happening in classrooms. In chemistry, this gap is especially visible. The subject naturally lends itself to experimentation, real-world application, and cross-disciplinary thinking-yet in many schools, it’s still taught in isolation, through lectures and textbook exercises. As a result, students may learn definitions and formulas, but they rarely get to do chemistry in a way that feels relevant or exciting. This study addresses that gap by developing a modular STEM-integrated unit plan tailored specifically to the 10th-grade chemistry curriculum. It aims to show how STEM concepts can be effectively combined with core chemistry topics to create engaging, meaningful learning experiences. In doing so, it responds to the real challenges teachers face, while also offering students a richer, more connected way to learn.

Background theories: This study draws on several well-established educational theories that support the shift from traditional instruction to more active, student-centered learning-exactly what STEM education promotes.

At its core, the research is grounded in constructivist learning theory, which suggests that students don't just absorb knowledge-they build it. According to this view, learning happens best when students engage with ideas through exploration, experimentation, and reflection. Jean Piaget and Lev Vygotsky, two of the most influential constructivist thinkers, emphasized the importance of hands-on experience and social interaction in developing deep understanding. These principles directly align with how STEM activities are structured: students work collaboratively, solve problems, test ideas, and revise their thinking based on feedback and real results.

Another important influence is experiential learning theory, especially the work of David Kolb. Kolb's learning cycle-concrete experience, reflective observation, abstract conceptualization, and active experimentation-mirrors the process students go through in STEM-based lessons. Rather than being passive recipients of information, students are placed at the center of the learning process. They try things out, see what happens, think about why it happened, and then apply what they learned to new situations.

The study also connects with the theory of multiple intelligences by Howard Gardner. STEM lessons naturally appeal to different types of learners-logical-mathematical thinkers, visual-spatial learners, kinesthetic learners, and more. By offering varied activities like model-building, data analysis, collaborative design, and digital simulations, STEM education gives more students more ways to succeed.

Finally, the research is informed by interdisciplinary learning theory, which encourages breaking down the walls between subjects. Rather than learning math, science, and technology in isolation, students explore how these fields work together in the real world. This approach reflects the actual way problems are solved outside the classroom-through teamwork, diverse perspectives, and a mix of skills.

Together, these theories provide a strong foundation for designing a STEM-integrated unit plan that is engaging, meaningful, and educationally sound. They remind us that real learning happens when students are actively involved-when they don't just study science, but do science.

Research Objectives

This study was driven by a simple but important goal: to create a chemistry lesson plan that actually works for both students and teachers-and that brings STEM to life in the classroom. More specifically, the research aimed to:

1. **Design an integrative STEM unit plan** that fits within the 10th-grade chemistry curriculum. The plan needed to reflect real-world problems and include tasks that combine science, technology, engineering, and mathematics-not just in theory, but in a way that feels practical and doable in everyday lessons.
2. **Implement the unit in a real classroom setting** to see how it actually plays out. Rather than just writing a plan on paper, the idea was to test it in action and observe how students respond, how teachers handle it, and what kind of learning takes place.
3. **Evaluate its effectiveness** by looking at both qualitative and quantitative data. This included analyzing test results, student feedback, and teacher observations to understand how the STEM approach impacted student engagement, conceptual understanding, and academic performance.

In short, the research set out not only to design a new approach, but to test whether it really makes a difference-and to gather insights that could be helpful for others who want to bring more STEM into their teaching.

Contribution of the Study

This study isn't just another academic project-it's a response to a real, everyday challenge faced by teachers in Kazakhstan and beyond. While a lot has been said about the value of STEM education, there's still a gap when it comes to actual tools that teachers can use-especially in subjects like chemistry.

Research contributes:

- **A ready-to-use STEM unit plan** for 10th-grade chemistry, built around real topics like atomic structure, reaction rates, redox reactions, and organic chemistry. It's structured, tested, and grounded in actual classroom experience.
- **Practical insight into what works-and what doesn't** when it comes to implementing STEM in a local school context. The study takes into account challenges like limited lab equipment, teacher confidence, and curriculum constraints.
- **Evidence of impact**: Through surveys, test results, and classroom observations, the study shows that the STEM approach can improve both how much students learn and how engaged they are in the process.
- **Support for teachers**: It offers a way forward for educators who want to teach differently but don't always know where to start. The unit plan isn't just theoretical-it's something teachers can take, adapt, and use.

In addition, this paper emphasizes that the integration of technology is a key element of modern pedagogy. In the modern information age, digital tools are not just complementary-they are important tools for increasing engagement, analyzing data, modeling real-world scenarios, and improving digital literacy. As Ismail, Permanasari, and Setiawan (2016) suggest, introducing technology into STEM curricula can better prepare students for modern work environments by encouraging them to approach problem solving with analytical and computational thinking. In addition to developing students' competencies, this study also examines the practical challenges faced by teachers, especially in the context of Kazakhstan. Although many teachers recognize the value of STEM education, they often lack the resources, professional training, or self-confidence to effectively implement interdisciplinary methods. Hassan, Riande, and Kaniawati (2022) have demonstrated that while professional development programs can expand teachers' knowledge and enhance the application of STEM principles, such as combining chemical concepts with the development of environmentally friendly materials such as bioplastics, it is difficult for many teachers to integrate scientific and mathematical knowledge into a design-based learning environment. This finding highlights the need not only for student-centered curricula, but also for teacher support systems that promote meaningful STEM integration. Ultimately, the goal of this dissertation is to develop and evaluate an integrative STEM lesson plan that will help 10th grade students think critically, solve problems, and innovate. The research uses constructivist methodology, interdisciplinary pedagogical strategies and technologies that enhance readiness for real life. In the following chapters, the methodology, design processes, implementation strategies, and results of this curriculum development project will be discussed in detail. Thus, this work aims to contribute to the growing number of studies promoting dynamic, student-centered approaches to science and mathematics education-approaches that are not only relevant, but also urgently needed in today's rapidly changing world.

THEORETICAL ASPECTS OF INVESTIGATION

1.1 Teaching chemistry in secondary school

In the article *"Teaching Chemistry in Secondary Schools: A Case for Cooperative Instructional Strategy,"* Dr. K.O. Aluko explores how cooperative learning methods can positively influence students’ achievement in chemistry. The study was motivated by a persistent issue in Nigerian secondary schools: students’ low performance in chemistry, despite numerous curriculum efforts and the subject’s importance in science and technology education. To address this, the researcher tested the effectiveness of a teaching approach called the Cooperative Instructional Strategy (CIS). The study involved 250 senior secondary school students from three public schools in Osun State, Nigeria. These students were divided into two groups: one was taught using the traditional lecture method, and the other using CIS. The cooperative method placed students in small mixed ability teams - 4-6 students - with the expectation they would work together to solve chemistry problems. The teacher acted more as a facilitator and did not act more as a lecturer. The construction of the cooperative method was grounded in a well established problem solving model where students would identify the problem, select other information relevant to identify possibilities of combining ideas, consider the various possibilities through evaluation of the various solutions to the problem. The cooperative method used in this study and the time frame of the study lasted six weeks, focused on two main topics from the chemistry outlines: the gas laws and the mole concept. Once the teaching period ended, both treatment groups completed an identical Chemistry Performance Test (CPT): a validated instrument designed to measure students' understanding and application of both topics. The results of the study were analyzed using ANCOVA to make valid claims about relative effectiveness of the two teaching strategies. The results were clear: students who were taught using the cooperative method appeared to significantly outperform students in the traditional group. Additionally, it was interpreted that this was determined equitable and the method was successful for both boys and girls. Also students with previous high, medium and low levels of achievement reported that they were able to take advantage of the cooperative method; the high achievers gained even more based on the study's results; but even the low achievers exhibited significant improvement. Dr. Aluko concludes that Cooperative Instruction Strategy is a practical and useful approach to improve students' learning of chemistry. Cooperative learning promotes problem solving, learning from peers, and engagement contributing to improvement of students' understanding and enhanced academic performance. The study recommended: that chemistry teachers make use of CIS in their classrooms, that progressive teacher education programs include some consideration of cooperative learning methods in their educational programs. Furthermore, it calls for educational stakeholders to support this shift through workshops, resources, and policy encouragement. Overall, this research supports the idea that student-centered, collaborative teaching strategies can make a meaningful difference in STEM education, especially in contexts where traditional methods have failed to engage learners or raise achievement levels. (Aluko, 2008)

One of the significant contributions to the study of how students are involved in chemistry education was the study of Abulude Francis Olawale (2009), in which he analyzed the attitude of schoolchildren to this subject in several schools in Akure South district (Ondo State, Nigeria). The main purpose of the work is to understand how students are interested in chemistry, what factors influence it, and how to improve their motivation.

To do this, the author conducted a survey among 300 high school students from five randomly selected schools. The survey used both standard questionnaires and statistical analysis methods. The results were alarming: most of the participants showed a negative attitude towards chemistry. More than 60% admitted that, if they had a choice, they would prefer not to study this subject at all. Many did not consider chemistry interesting and certainly did not plan to associate their future education with it.

Why is this happening? The study showed that this is the result of several factors at once-from the complexity of the subject itself to the learning system. The students complained that chemistry seemed to them too abstract and divorced from real life. Complex terms, formulas, symbols, and theories often only scared them away, causing a sense of misunderstanding and rejection.

An equally important factor was the lack of educational resources. Schools lacked modern textbooks, experimental equipment, and visual materials. In such conditions, students perceived chemistry exclusively as a theoretical science, boring and far from practice.

The teachers themselves created an additional difficulty. Many students noted that their teachers were not inspiring, were too strict, and still used outdated teaching methods, such as memorizing material and explaining "at the chalkboard." This did not contribute to engagement: critical thinking did not develop, and interest waned. The lack of an individual approach also complicated the process-strong and weak students found themselves in the same losing position. Parental influence and broader societal views also played a role. In several cases, students reported that parents and older siblings portrayed chemistry as extremely difficult, discouraging them from putting effort into mastering the subject. As a result, students internalized a fear of chemistry before even engaging with it in a structured learning environment.

The results of the study were supported by quantitative data:

- 73.3% of students stated that they found chemistry too difficult.
- 64.3% admitted they often could not understand what was being taught.
- 71.3% did not enjoy solving chemistry problems, particularly calculations and abstract exercises.
- Alarmingly, 86% agreed that chemistry could be removed from the school curriculum without significant consequence to their future.

These statistics paint a clear picture of disengagement and underscore the urgency of reform in chemistry education, particularly in under-resourced contexts.

In light of these findings, the study proposed several practical recommendations. First, the need for continuous professional development of teachers was emphasized. Teachers should participate in workshops, in-service training, and ongoing pedagogical development programs to learn innovative, student-centered teaching strategies. Second, the government and educational stakeholders must ensure that schools are equipped with modern laboratories, updated textbooks, and digital learning aids to enhance practical learning experiences. Third, student motivation should be cultivated through active learning methods, including group work, inquiry-based activities, and real-life problem-solving tasks. Finally, the study recommended that parents and communities become more actively involved in promoting science education by reshaping perceptions and encouraging positive attitudes at home.

This research is especially relevant in the context of contemporary STEM education reforms. While the study did not explicitly examine STEM integration, its findings strongly support the core principles of STEM pedagogy: relevance, engagement, contextual learning, and interdisciplinary connections. In fact, the lack of real-world applications and limited interdisciplinary approaches described in the Nigerian schools mirror the same problems that STEM education seeks to overcome. Therefore, the study by Abulude provides important groundwork for understanding why STEM-based methods may be more effective in shifting students' attitudes towards chemistry-particularly in developing educational systems where student motivation and infrastructure are ongoing challenges. (Abulude, 2009)

In the article *"Teaching Chemistry in High Schools"* (Jumamuratov & Kaipbergenov, 2023), the authors explore practical and philosophical aspects of improving chemistry education in secondary schools. Drawing on their teaching experience and pedagogical reflections, they argue that modern chemistry instruction must go beyond content delivery and focus on creating an engaging, inquiry-based, and student-centered learning environment. The article emphasizes that in the current era of rapid scientific advancement and information overload, the role of the teacher is no longer limited to transmitting static knowledge, but instead involves guiding students in how to independently acquire, interpret, and apply information through active learning strategies.

One of the key objectives of the article is to rethink the structure of chemistry lessons to foster cognitive engagement and sustained interest in the subject. According to the authors, meaningful learning in chemistry occurs when students are involved in discovery-oriented activities, such as frontal experiments, research lessons, and problem-solving tasks, rather than passive memorization. Jumamuratov shares examples from classroom practice, including the use of collaborative experiments (e.g., exploring the combustion properties of oxygen), student-driven hypothesis testing, and the construction of conceptual maps to explain chemical behavior-such as the variable oxidation properties of nitric and sulfuric acids.

Another central theme of the article is the integration of information and computer technologies (ICT) into the chemistry classroom. The authors describe the use of digital tools and multimedia platforms to simulate complex processes, visualize molecular structures, and model chemical reactions. This includes dynamic visualizations of atom structures, virtual labs, and digital test banks designed to assess conceptual understanding. In doing so, the authors advocate for a blended learning environment where ICT acts as both a cognitive scaffold and an emotional stimulus, helping students to form deeper mental images of abstract content, particularly in topics such as organic chemistry or atomic theory.

Most importantly, the article does not contrast information and communication technologies (ICT) with traditional laboratory experiments. On the contrary, they are considered as an effective complement, especially in cases where practical experiments are limited due to security reasons, lack of time or resources. The authors emphasize that virtual experiments can act as preparation for real laboratory classes — they allow students to analyze procedures in advance, understand the expected results, and thus make practical work in the laboratory more focused and productive. In addition, such digital tools contribute to the development of students' reflection skills, as students learn to plan actions, analyze results, and compare theoretical assumptions with observable data.

From a methodological point of view, the work is descriptive and practice-oriented, rather than strictly empirical research. The basis of the material is the pedagogical experience of the authors, as well as their educational philosophy, and not the data obtained through formal methods of information collection or statistical analysis. Nevertheless, the presented research is characterized by rich pedagogical content and offers valuable methodological approaches that comply with the principles of constructivist and student-oriented learning.

In conclusion, the article highlights that effective chemistry teaching requires a combination of didactic innovation, emotional engagement, and technological support. By shifting from a traditional, teacher-centered model toward a more interactive and exploratory approach, educators can foster not only knowledge retention but also independent thinking, problem-solving skills, and long-term motivation to learn. The authors argue that such transformations are essential if chemistry education is to meet the needs of a rapidly changing world and prepare students for further study and careers in STEM fields. (Jumamuratov & Kaipbergenov, 2023)

In her 2019 article *“Innovative Approaches in Teaching Chemistry in Digital Era at Secondary School Level in Nigeria,”* Amina Aminu explores how technology-enhanced and student-centered instructional strategies can address long-standing challenges in chemistry education. The paper presents a conceptual and practice-based discussion that emphasizes the importance of innovative, interactive, and digitally supported methods to make chemistry more accessible, engaging, and effective for secondary school students.

The core argument of the article is that the traditional approach to teaching chemistry-based heavily on rote memorization and teacher-centered delivery-fails to meet the needs of contemporary learners. In the context of the digital era, Aminu advocates for a shift toward active learning methods that include laboratory work, problem-solving, process-oriented guided inquiry (POGIL), collaborative learning, and the integration of digital tools such as simulations, videos, and computer-assisted instruction. These approaches, according to the author, not only support students in mastering content but also promote critical skills such as analytical thinking, teamwork, and independent inquiry.

One of the strengths of the article lies in its classification of "contextual orientations" in chemistry education. Drawing from the work of Eilks and Hofstein (2013), Aminu highlights several thematic approaches to structuring curriculum: historical, disciplinary, environmental, industrial, and socio-scientific. These orientations serve as entry points to develop chemistry lessons grounded in real-life relevance, which in turn can enhance motivation and conceptual understanding. The strategy of contextual deconstruction and reorganization, as described in the article, supports cumulative learning and helps students form flexible and transferable knowledge frameworks.

The article further discusses digital learning environments, such as blended learning, game-based learning, and the use of virtual laboratories. These tools are presented not as replacements for traditional instruction but as enhancements that can compensate for gaps in equipment, classroom time, and student engagement. Aminu also stresses the importance of teacher digital literacy, professional development, and the need for reliable infrastructure, particularly electricity and internet connectivity, which remain critical obstacles in many Nigerian schools.

From a practical standpoint, Aminu identifies several issues in teaching chemistry today, including lack of trained personnel, inadequate laboratory facilities, funding constraints, examination malpractice, and low student motivation. To address these challenges, the article offers a series of policy-level recommendations, such as increased investment in e-learning infrastructure, hiring and training qualified chemistry teachers, and incorporating research-based teaching methods into mainstream education.

Overall, this work contributes significantly to the discourse on reforming chemistry education through the lens of 21st-century pedagogy. It aligns with broader STEM education goals, emphasizing not only content mastery but also the development of transversal skills and learner autonomy. Aminu's insights underscore the urgency of rethinking both curriculum and instruction to prepare students for the complexities of scientific understanding in a digital and knowledge-driven age. (Aminu, 2019)

In the 2024 review article titled *"Challenges for Effective Teaching of Chemistry in Secondary Schools of Developing Countries,"* Berhe, Tesfemariam, and Weldemichael provide a broad and insightful examination of the barriers that continue to hinder quality chemistry education in many developing nations. Although chemistry plays a vital role in preparing students for careers in science, engineering, and medicine, its teaching remains deeply challenged by a combination of pedagogical, infrastructural, administrative, and cultural factors.

The main purpose of the review was to identify the most persistent challenges affecting chemistry instruction and to analyze them based on existing literature. To achieve this, the authors reviewed twelve research papers published over the past decade, sourced from databases such as Web of Science, ERIC, and Google Scholar. For the purposes of this review, studies were selected based on connection and geographic diversity - highlighting the educational systems across Africa, Asia, and Latin America.

The review noted six key limitations in chemistry teaching:

Negative student attitudes towards chemistry (often considered difficult, too abstract, and not relevant to their lives). Generally exacerbated by bad teaching practice, failure to contextualize or relate to social biases, such as gender, for girls entering science subjects.

Poor and inadequate laboratory infrastructure. Students are challenged to develop practical skills and relate theory to practice when they have had no hands-on experimental work because their school simply has no suitable laboratory set-up.

Teaching inadequacy and poor teaching practice. A reliance on being lectured to, limited pedagogical content knowledge, and generally, the chemistry teacher not having appropriate pedagogy. Many chemistry teachers do not undergo any teacher education qualifying, let alone being accountable for using more modern student-centred practices.

Overcrowded classrooms. Teachers are unable to support individuals in large class sizes and create an interactive lesson. Class sizes are a particular challenge for science education where practical activities rely on reasonably sized groups.

Curriculum overload. Here, the chemistry syllabus, where it exists, is often compelled, inflexible and disconnected from what students experience or the local context. Some are based on unilateral copying foreign drawn models, creating further disconnect for students to identify and apply to.

Weak educational leadership. In the review, the systemic issues emerged, such as poor leadership, under-funding, lack of support for teachers, lack of support for teacher capacities, and poor professional development opportunities, are common across many school systems. There was inconsistency in policy implementation and incentives offered to teachers, however were delayed or non-existent.

The authors highlight these challenges are interrelated. For example, poor laboratory infrastructure influences teacher demotivation, thus affecting students' interest and participation outcomes. As another example, many curriculum issues were often compounded by administration neglect and teacher shortages.

Nevertheless, the authors recommend that there needs to be a collaborative, multi-level system response including teachers, school leaders, education authorities, community and families. The following need to be included: improving infrastructure, particularly with respect to science laboratories, curriculum that is reflective of local needs and experiences; on-going teacher training needs to be adequate professional support; and improved financial and institutional support from educational authorities.

This article is especially valuable in the context of STEM education reform, as it offers a holistic understanding of the systemic obstacles facing chemistry education. It also reinforces the view that true improvements in science instruction require more than updated content-they demand changes in the entire educational ecosystem. (Berhe et al., 2024)

This qualitative research conducted by Nja (2021) provides a rich exploration of secondary school students’ perspectives on effective teaching methods in chemistry and the motivational factors behind their subject choice. Rooted in brain-based learning theory, the study emphasizes the cognitive and emotional conditions that optimize student engagement and conceptual understanding in science education.

The study was carried out in a coeducational senior secondary school in Calabar, Nigeria, with a sample of 28 SS3 chemistry students aged 15 to 21. Data collection was performed using an open-ended questionnaire comprising two core questions: (1) why students chose to study chemistry and (2) how they would teach it if given the opportunity. Thematic coding and descriptive statistics revealed that approximately 68% of students selected chemistry because of its relevance to their future careers, such as medicine, engineering, and nursing. Around 32% chose it out of genuine interest or enjoyment.

Most notably, over 60% of the participants stated that they would teach chemistry using practical examples and materials from everyday life, particularly the kitchen environment. This aligns with the theoretical underpinning of spatial learning and environmental relevance proposed by brain-based learning theorists such as Caine and Caine (1990). Students emphasized the importance of contextualized teaching, emotional comfort in the classroom, humor, and interactive methods to make chemistry more relatable and memorable.

The findings underscore the limitations of traditional lecture-based instruction and suggest the necessity of adopting more student-centered, practical, and emotionally engaging approaches. The research supports the broader STEM education movement, advocating for integration of real-life scenarios and hands-on activities to foster deeper understanding and long-term retention.

This study is highly relevant to the current dissertation, as it highlights the direct relationship between student motivation, pedagogical approach, and learning outcomes in chemistry. It also validates the need for reforming classroom practices to reflect learner preferences and contextual realities, especially in resource-constrained educational settings. (Nja, 2021)

1.2 Teaching chemistry with integrative manner

In the 2019 study, *Developing Critical and Creative Thinking Skills through STEAM Integration in Chemistry Learning*, Rahmawati and colleagues explore how integrating STEAM principles into chemistry lessons can help students think more critically and creatively. The researchers worked with 76 eleventh-grade students from two Indonesian secondary schools and focused on one particular chemistry topic-acids and bases. Rather than teaching it through traditional lectures, they used a project-based learning model, where students were tasked with building and managing hydroponic systems to grow plants.

This hands-on project wasn’t just about chemistry. It brought in elements from other disciplines: students applied science to test pH levels, used technology to monitor conditions, applied engineering and mathematics to design and measure their hydroponic systems, and even used art to create visually appealing setups. The idea was to encourage students to solve real-life problems and see how different fields come together in the learning process.

Throughout the project, the students were guided to ask questions, seek out different sources of information (books, internet, observations), experiment with solutions, and reflect on what they learned. These are exactly the kinds of behaviors that support the development of critical and creative thinking skills. For instance, some students discovered that their plants were dying due to unsuitable pH levels and had to figure out how to adjust their nutrient solutions. Others rethought the placement of their systems based on sunlight or airflow - applying chemistry in a meaningful, problem-solving context.

The study showed that students became more engaged and better at thinking independently, especially when they worked in teams. They didn't just memorize concepts - they applied them, questioned them, and sometimes even challenged them. Their reflections showed increased confidence in their ability to solve problems creatively and logically.

At the same time, the researchers note that introducing an interdisciplinary approach to chemistry teaching is not an easy task. It is especially difficult to do this in conditions when the school curriculum is still clearly divided by subjects. Lack of time, limited resources, and insufficient support from the education system were identified as the main barriers. Nevertheless, the authors emphasize that despite all the difficulties, the STEAM approach allows you to create deeper and more meaningful educational experiences. It helps students develop those types of thinking that are especially in demand in the world of the future.

This study will be especially useful for those who are interested in integrating STEM and STEAM into chemistry teaching. It shows how even a relatively simple project-for example, growing plants using hydroponics-can turn an ordinary chemistry lesson into a vibrant interdisciplinary experience. Moreover, when students are given the opportunity to explore, create, and work in a team, their thinking goes far beyond the textbook.

STEM is not just about science, technology, engineering, and mathematics. It is a way to connect different fields of knowledge in a way that helps students better understand the world around them. According to Kennedy and Odell (2014), STEM education begins with scientific research-from the moment when a student asks an important question and seeks an answer to it. This process prepares him for the next stage, engineering thinking, where the knowledge gained is applied to solve real-world problems. This approach reflects real life: multi-layered, complex, without ready-made answers.

We live in a world that is rapidly changing. The challenges facing society require flexibility and a broad view. This dissertation takes this reality into account and aims to prepare students not only in terms of knowledge, but also in terms of the thinking, critical analysis, and adaptability they will need in the future. At the same time, the work honestly recognizes the difficulties that teachers in Kazakhstan may face when implementing STEM: from lack of equipment to system limitations. The dissertation attempts to approach these problems with understanding and constructiveness.

The theoretical basis of the research is a constructivist approach to learning, according to which the student builds his own understanding, and not just receives ready-made information from the teacher. Knowledge is formed through experience, discussion, practice, and reflection. Applying this approach to the development of an integrative STEM unit plan means creating an active educational environment in which students are not afraid to ask questions, explore, test hypotheses, and learn from each other while solving real-world problems.

Technology plays a key role in this process. In the era of digital transformation, it is important for students not only to know the subject, but also to be able to navigate the information flow, critically evaluate sources and confidently apply digital tools. As Ismail, Permanasari, and Setiawan (2016) emphasize, the integration of technology into STEM helps connect schooling with the real world and prepare students for the demands of a modern profession. In this paper, special attention is paid to digital tools as a way to enhance learning, develop students' confidence and form key skills of the 21st century.

Ultimately, the goal of this work is to design a flexible, engaging, and practical Integrative STEM Unit Plan tailored specifically for 10th-grade students. It aims to show how interdisciplinary education - rooted in constructivist principles and supported by thoughtful use of technology - can nurture curiosity, creativity, and critical thinking. These aren’t just academic goals; they’re life skills that students will carry with them long after the lesson ends. The following chapters will explore how this curriculum was developed, implemented, and evaluated, revealing what it takes to move beyond traditional subject silos and build something that truly prepares students for the future. (Kennedy & Odell, 2014)

“Teaching and Learning STEM: A Practical Guide” by Richard M. Felder and Rebecca Brent isn’t just another textbook about how to teach. It’s a refreshingly down-to-earth and practical guide for educators in science, technology, engineering, and mathematics - the kind of book that feels like it was written by real teachers who have faced real challenges in real classrooms.

At the heart of this book is a simple yet powerful message: students learn best when they are actively involved in the process. The traditional lecture-based model, where the teacher talks and students passively take notes, just doesn't cut it anymore - especially in STEM fields, where critical thinking, problem-solving, and creativity are essential. Felder and Brent offer a better way: learner-centered teaching. This means creating a classroom where students aren't just listening - they're doing, questioning, reflecting, discussing, and applying what they learn.

One of the standout aspects of the book is how much attention it gives to learning objectives. This may sound like a dry topic, but the authors show how writing clear, specific, and observable objectives is the key to building a coherent and effective course. Good objectives help instructors design lessons that actually lead somewhere, and help students understand exactly what's expected of them - no more guessing games before exams.

The book also dives into the nuts and bolts of course planning: how to write a syllabus that's not just a list of topics, how to grade fairly, how to get a class off to a strong start. It offers simple checklists and strategies that make preparing a course feel manageable, even for new instructors.

What really makes this guide come alive, though, is its emphasis on active learning. The authors don't just tell you it's important - they show you exactly how to do it. Whether you're teaching 30 students or 300, they provide examples of activities, group work strategies, and low-prep techniques that get students talking, thinking, and participating. They also walk you through common pitfalls and how to avoid them.

Another strong point is their balanced approach to technology in teaching. Rather than jumping on every new digital tool just because it's trendy, the authors focus on how to use technology to enhance, not distract from, student learning. They explore flipped classrooms, blended learning, and online course strategies in a way that feels grounded and intentional.

Beyond content knowledge, Felder and Brent emphasize the importance of helping students develop professional and lifelong learning skills - communication, collaboration, critical thinking, self-direction - the kind of skills that matter in the real world. The book offers ways to build these into STEM courses through project-based learning, peer feedback, and problem-solving tasks that mirror real-life challenges.

One of the most refreshing parts of the book is its honesty. The authors don't pretend that shifting to more student-centered teaching is always smooth. They acknowledge that students might push back - especially if they're used to passive learning. But they also provide strategies for dealing with that resistance, and they offer reassurance: it gets easier, and the results are worth it.

The book doesn't ask you to flip your entire teaching style overnight. In fact, the authors recommend starting small - one new method, one new activity, one new strategy at a time. It’s this realistic, empathetic tone that makes the book so valuable. It’s clear they’ve been there, struggled through the same challenges, and come out the other side with a deeper, more fulfilling way to teach.

In the end, *“Teaching and Learning STEM”* is about more than teaching techniques. It’s about creating a classroom where students don’t just survive STEM - they thrive in it. It’s a must-read for any STEM educator who wants to move beyond old habits and build courses that inspire real learning. (Felder & Brent, 2016)

A significant contribution to the discourse on modern chemistry education is presented in the article *“Integrative Chemistry Teaching”* by Hagverdiyev and Mammadova (2021), which explores the theoretical and practical implications of adopting integrative pedagogical approaches in secondary and tertiary chemistry instruction. The authors argue that in order to prepare intellectually developed individuals capable of navigating a complex, interconnected world, modern education must adopt a holistic, interdisciplinary perspective. In this context, integration is not merely a trend but a necessity, providing opportunities for self-expression, creativity, and deeper understanding among students and educators alike.

The paper defines integrative chemistry teaching as a structured process that harmonizes various pedagogical components-goals, content, methods, tools, technologies-into a coherent and adaptive framework. The authors emphasize that the success of this model lies in the effective fusion of interdisciplinary connections, cognitive-emotional engagement, and real-world relevance. Central to this approach is the recognition that chemistry cannot be taught in isolation from other disciplines; instead, it should be linked with physics, biology, environmental science, and even social and technological domains to reflect its real-world applications.

One of the core ideas advanced in the paper is the importance of using integrative educational technologies (IET), which encompass both traditional and innovative teaching methods, multimedia tools, and modular training systems. These technologies aim to develop students' universal competencies, enhance problem-solving skills, and foster positive attitudes toward lifelong learning. The authors also introduce the concept of integrative-modular teaching (IMT) as a promising method for structuring chemistry curricula. IMT allows for the division of content into modular blocks that align with cognitive and functional learning objectives, thereby enabling differentiated instruction and continuous assessment.

Furthermore, the article highlights the critical role of chemistry teachers in mastering and applying integrative strategies. Teachers are expected to understand the laws of integration within pedagogical contexts and utilize them effectively in both content delivery and student evaluation. The authors advocate for training chemistry educators in the application of integrative techniques, including problem-based learning, cross-disciplinary activities, and innovation-driven lessons. This approach not only improves academic achievement but also prepares students for professional environments where interdisciplinary thinking is essential.

In terms of results, the study draws from years of empirical teaching experience and concludes that integrative chemistry teaching-when supported by methodological precision, appropriate technological tools, and pedagogical innovation-significantly improves both the quality of instruction and student engagement. The authors assert that only through such integrative strategies can future chemistry professionals be trained to thrive in the competitive and dynamic socio-economic landscape.

This article is particularly relevant to the present dissertation as it supports the notion that STEM-based, interdisciplinary approaches in chemistry teaching are more effective in developing not only subject mastery but also transferable skills critical for 21st-century education. Its emphasis on modular teaching, ICT integration, and learner-centered design aligns well with the goals of creating a sustainable and scalable STEM curriculum for secondary education. (Hagverdiyev & Mammadova, 2021)

The study by Fitriyana et al. (2024) explores the perceptions of high school chemistry teachers (HSCT) and vocational school chemistry teachers (VSCT) in Yogyakarta, Indonesia, regarding the integration of STEM (Science, Technology, Engineering, and Mathematics) into chemistry education. Using an explorative survey method, the researchers gathered quantitative and qualitative data from 131 in-service chemistry teachers through the PC-STEM instrument, which consisted of 54 closed-ended items and 7 open-ended questions. These instruments were designed to assess knowledge, perceptions, and experiences related to STEM-based chemistry teaching.

The findings reveal that HSCTs and VSCTs had generally favorable perceptions of STEM integration as it helped to demonstrate that chemistry could be useful, relevant, and interesting as applied to real-life contexts. Teachers shared that STEM learning allows for the strengthening of students’ critical thinking, problem-solving, and creativity skills, while providing meaningful contexts by linking the abstract concepts taught in chemistry to real life applications. For example, participants mentioned STEM integration through projects they had done such as creating fruit powered batteries and creating antioxidant-rich ice cream where they used redox reactions and freezing point depression.

Nonetheless, the study found some significant challenges. Despite the generally favorable perceptions, most teachers had no practical experience implementing STEM-based chemistry lessons. Some challenges included insufficient time, inadequate facilities and materials, and little professional development in STEM pedagogy. Many of the teachers were willing to integrate STEM, but only believed certain topics in chemistry could be integrated (i.e., redox, electrochemistry) while also indicating gaps in the chemistry curriculum as well as gaps in their own pedagogical readiness.

To examine group differences, a one-way multivariate analysis of variance (MANOVA) was conducted, and there were no statistically significant differences between HSCT and VSCT populations in their overall perceptions of STEM. However, HSCT had slightly higher mean scores of their overall perceptions of STEM which may indicate more frequent participation in STEM-based professional development activities.The results suggest that while the potential for STEM is well recognized, the success of STEM in chemistry education hinges on building teachers' TPACK (Technological Pedagogical Content Knowledge) and developing curriculum support for teachers, and proximity to training.

Overall, in conclusion, the article emphasizes the need for teachers capacity building and institutional support to have effective STEM activities in secondary chemistry classrooms. The article also suggests ongoing teacher development and teachers can work together (e.g. MGMP teacher groups) to convert positive perceptions into effective practice in the classroom.(Fitriyana et al., 2024)

The article "Modes of Technology Integration in Chemistry Teaching: Theory and Practice" by Aroch, Katchevich, and Blonder (2024) published in Chemistry Education Research and Practice provide a detailed qualitative study of technology integration in secondary chemistry education. As part of TPACK (Technological Pedagogical Content Knowledge), the study in this article investigated different modalities experienced chemistry teachers used to incorporate digital technology into online remote teaching, ranging from seven modes of teaching described as modes of technology integration or MOTIs. These modes when taken altogether can be viewed as an overt method for teachers to implement digital tools, alongside pedagogical activities that provide student understanding of content and instances of teaching effectiveness in an secondary chemistry classroom.

The research took two phases. In the first phase semi-structured interviews were conducted with 5 veteran chemistry teachers focused on their individual experiences in using digital technology while participating in remote teaching.The authors found that through qualitative coding and thematic analysis, there are seven common modes of integration: use of digital technologies related to visualization, digital online open access databases, use of computational methods, virtual labs and video demonstrations, support for multi-level representations of concepts, expanded access to scientific research, and context framing in chemistry through everyday scenarios. It is interesting to note while the first four modes aligned with practices that had been previously reported in the educational literature, modes five through seven were new and did not appear to have been previously documented. Moreover, these new modes particularly highlight context-rich learning and student access, which generally aligns with recent trends in learner-centered and socially embedded science education.

The second stage of the study involved finding a methodological way to validate the findings gathered through the qualitative coding and thematic analysis. The authors did so by surveying another group of 22 chemistry teachers to get a sense of whether they felt the modes of integration were relevant, and whether they viewed them as feasible. The results of the survey justify the importance of these modes of integration relative to the teaching and learning of chemistry. Interestingly, the survey points out that experienced teachers understand, appreciate, and use the versatility of technology, and that they can draw on the modes of integration through pedagogical considerations in regard to how they interact with their students when teaching.

A key takeaway from the study is the awareness of and classification of the modes helps improve our understanding of how to effectively relate technology in a meaningful way to support chemical education. The authors have documented modes that are well-established with some that are new and emerging thinking sharply outlining how teachers could organize choosing the appropriate technology by documenting their practices. The findings of the study emphasize a need for teacher education programs that train future educators on how to enact a variety of modes of integration in an effective way. As the authors state, the intentional use of digital technologies has the potential to positively transform the teaching and learning of chemistry for students making it more accessible and relevant to the world they live in.

This is a wonderful piece of research to inform professional development and curriculum development in STEM education - especially when they highlight that technology integration is not just a black box, but it is actually a series of nuanced practices that involve pedagogical insight, subject-matter expertise, and technological fluency. In relation to the current dissertation, these findings are supportive of the literature on promoting integrated and richly technological chemistry contextualized for deeper learning which can lead to improved student learning outcomes. (Aroch et al., 2024)

1.3 Creating integrative unit/chapter plan in chemistry

In the article "A Modern Sample of Integrative Teaching and Learning within Chemistry Lessons" Ravan Mammadov describes in a rich and concrete way how chemistry teaching can become alive and vibrant through integration with other subjects such as biology, physics, and mathematics. Through the lens of actual experience in Azerbaijan, Mammadov demonstrates how contextual teaching through integration can help students learn chemistry concepts not only as abstract theories, but as concepts linked to the world in which they exist.

The crux of the article features a detailed integrative lesson on electrolytic dissociation. Instead of remaining in the textbook, students make, perform, and take part in experiments and group investigations-oriented to the topic. For example, students determine the conductivity of various solutions, see what is happening to temperature during dissolution reactions, and even get to witness what happens to the biological reaction of a frog's muscles in a weak electric current. Even though these activities are amusing, they are engaged in chemistry, biomimicry, and physics to increase students' questions and curiosity.

Mammadov describes a combination of methods including brainstorming, discussion, hands-on experiments, and digital presentations using problem solving. New groups are formed producing small groups of researchers, and each small group of researchers examines a particular aspect of the topic utilizing existing knowledge from different subjects. One small group examines chemical structure and bonding, other small groups investigate ions found within living cells and other small groups use physical principles including Coulomb's law, or model it mathematically. The goal is to prompt students to look beyond "boundaries" of subjects, and see themselves not only as learners of chemistry, but as scientists making sense of the complexity of the system.What is particularly compelling is the way this work changes the role of the teacher. Instead of being a "lecturer," the teacher can be a facilitator or guide. In this activity, students were encouraged to generate hypothesis, test those hypotheses and report back their results, and at the end, give presentations on their work as if they were young scientist. Mammadov's data indicate that this increased student engagement, understanding, and ability to solve problems. As an example, students in an integrated course independently solved about 80% of the tasks, whereas in traditional teaching, they engaged with, on average, only 30% of the tasks.

The article concludes with a message that should resonate with all science educators: integrative teaching is not just a nice idea, it works; it helps students make connections, it fosters creativity, and makes critical thinking visible. Most importantly, it prepares them for situations in the real world where knowledge is not presented in isolated subject areas. Mammadov's work shows how chemistry education can transform into a more meaningful, useful, and connected form - to the world they are living in. (Mammadov, 2015)

Clayton R. Squire's project, "An Integrated Biology and Chemistry Curriculum," offers a refreshing and optimistic alternative to one of the greatest impediments of secondary science education in our schools - learning science in schools with little connection to how science works in the real world.Instead of continuing with the conventional "layer cake" model- in which students learn one science in isolation from another each year-Squire proposes something less piecemeal, and more meaningful, and more relevant: an integrated, two-year program that relates biology and chemistry in a coherent and student-centered way.

What makes this work so impressive is not only the ambitiousness of the agenda; it is the fact Squire's work is very much grounded in classroom reality. Developed with a group of teachers at University High School in San Francisco, Squire's approach to a two-year integrated curriculum is predicated on the idea that biology and chemistry are naturally intertwined-and therefore there is a real advantage for students when they are offered these disciplines in the same context. For example, there is little value in teaching DNA instruction without an understanding of what molecules, atoms and chemical bonding are. Another example would be respiration or digestion. These two topics are often taught individually and similarly robbed of their chemistry. By showing how biology and chemistry rather mutually support each other, Squire demonstrated that students, when offered biology and chemistry collaboratively together, actually developed a more complete and useful understanding of the respective specializations.

Another significant strength of the biology-chemistry integrated curriculum documented in Squire's work is found in its foundation upon constructivist learning theory. Rather than treating students as passive vessels for knowledge, in this integrated course, students have existing understandings-accurate, inaccurate or somewhere in between-and meaningful learning takesThe structure of the curriculum embodies this notion: Year 1 introduces students to concrete, observable topics such as the human body or the properties of gases; Year 2 introduces students to more abstract concepts such as the structure of an atom or chemical representations. This order is not happenstance-it is an aligned plan; a reflection of how students build a foundation of understanding from their cognitive process.

Another notable feature of this curriculum is its focus on how students learn, not just what they learn. Lessons are framed using an inquiry model: students begin by exploring an idea or concept through observation or hands-on activities; work collaboratively to define the dimensions of the principle; then apply what they learned to a new context. This triadic cycle allows students to think about the concept rather than just repeating facts. In addition, the learning structure offered is shared. Students engage in group projects, student interest assessments, and peer-teaching opportunities. This emphasizes that science is seldom a solitary endeavor-it occurs as a collaboration, as dialogue, as a joint search for the solution.

The curriculum also considers equity and inclusiveness in a well-defined way. It is not about providing modified programs for underachieving students; rather, it is about privilege broadening the entry point for entry and content and clarification over content recall. It is not simply about providing content; it is about extending all learners, regardless of prior experience or academic history, an invitation into science. One of the most exciting features of this design is the framing of the instruction as not track-meaning that one of the worst treatments of students is to being assigned a lower level science or course. All students are treated as if they can contribute to scientific ideas and operate in a way that builds a culture of belonging.

When it comes to assessment, the curriculum is framed beyond multiple-choice. Rather, it uses the lab notebook and written reflections to assess and self-identity progress, along with open note tests; reasoning and communication are more important than fact memorization here. There is a clearly articulated goal of making students think like a scientist rather than behave like a student. Finally, even how students are assessed is congruent with a constructivist philosophy-there is growth, self-reflection, and making sense of ideas.

The lesson plans included in the project bring everything together. They are full of creative, engaging activities that are designed to spark curiosity and make learning feel real. One standout example involves showing students a moving drop of mercury and asking if it's alive-prompting a deeper investigation into the characteristics of life and the nature of scientific observation. Another lesson has students explore Boyle’s law through hands-on experiments before being told what it is, letting them “discover” the law themselves. This kind of teaching makes science exciting, memorable, and, most importantly, student-driven.

In the end, this curriculum is about much more than blending two subjects. It’s about rethinking what science education could be if we stopped separating disciplines, removed barriers for students, and gave them the chance to explore science as a living, connected, and empowering process. Squire doesn’t just talk about integrating content-he integrates learning, thinking, doing, and reflecting. His work is a powerful reminder that science education can be rigorous and human at the same time. It’s the kind of approach that not only prepares students for exams but for real understanding-and for life. (Squire, 1995)

The *Integrated Chemistry & Physics Curriculum - 2023 Update* developed by Centerville Senior High School is a great example of how science education can be both academically rigorous and highly engaging. Instead of teaching chemistry and physics as completely separate subjects, this curriculum brings them together into one cohesive experience - helping students see how scientific concepts connect and apply to the real world.

One of the things that makes this curriculum stand out is its structure. It’s divided into clear, themed units like Motion and Forces, Energy, Waves, Matter, and so on - each one tied to meaningful, real-world questions and ending with hands-on performance tasks. For example, in the first unit, students roll different balls into a stationary softball to explore momentum and Newton’s laws. They collect data, calculate velocities and momentum, and use graphs to draw conclusions. Instead of just reading about these concepts in a book, they experience them firsthand.

Throughout the curriculum, there’s a strong focus on student engagement. Lessons include experiments, collaborative group work, visual learning tools, interactive simulations, and digital platforms like Quizlet and SmartBook. There’s even creative stuff like “Periodic Table Bingo” to help students learn in a fun, low-pressure way. The curriculum designers clearly understand that students don’t all learn the same way - and they’ve made sure there’s something here for everyone.

The learning targets are written in a student-friendly way, using “I can” statements that are easy to understand and focus on real skills. Things like “I can calculate the half-life of a radioactive material” or “I can explain how thermal energy is transferred” help students keep track of what they’re learning - and help teachers focus their instruction.

But what really brings this curriculum to life is how it connects learning to authentic, real-world tasks. Every unit ends with a hands-on project that ties the content to something practical. In the energy unit, students calculate how much power they use running up stairs. In the nuclear energy unit, they use M&Ms to simulate radioactive decay and make the intangible tangible in a fun way, which is far more powerful than simply learning about the concept and applying it. These opportunities don't just facilitate student learning, they also make student learning more enjoyable and meaningful.

To that end, the curriculum is structured to support a larger suite of academic skills too. In addition to understanding information about science as a subject, students learn through reading scientific texts, data tables, data analysis, scientific process explanations, explanations of scientific processes, and through critical thinking. They provide academic stems to help guide class discussions and enhance critical thinking. The assessment goes beyond simple quizzes to include labs, reflections, and data analysis too.

It’s also worth noting how well-aligned the curriculum is with academic standards - especially the Indiana state standards. It doesn’t just check boxes, though. It uses the standards as a foundation while still giving teachers and students room to explore, ask questions, and get creative.

Overall, this curriculum is a thoughtful blend of classic science content, modern teaching methods, and student-centered design. It’s active, engaging, and real - the kind of curriculum that doesn’t just teach students to remember science, but to live it. For anyone working on developing integrated STEM lessons or designing interdisciplinary science units, this curriculum offers a strong, practical example of how it can be done effectively. (Lair & Maule, 2023)

The work of Jumabai et al. (2024) is devoted to the study of the effectiveness of the STEM course for future mathematics teachers in the context of their professional development and the formation of confidence in their own pedagogical capabilities - the so-called self-efficacy. The authors emphasize that STEM education plays a key role in preparing young people for the challenges of the 21st century, and its impact on the development of society is increasing every year. In this regard, the issue of training teachers themselves becomes particularly relevant, who should not only have knowledge in the field of STEM disciplines, but also be able to integrate them into a single educational process. The study was conducted with the participation of 52 students of the master's degree in mathematics from Kazakhstan, who completed an online course on STEM education. This course included both theoretical and practical components: lectures, discussions, assignments, project work, developing your own lesson plans, as well as watching and analyzing video materials. The main goal of the course was not only to transfer knowledge about the STEM approach, but also to create conditions for future teachers to gain experience that they can apply in their professional activities. The learning process was organized taking into account the principles of active learning, interaction in a digital environment, as well as summarizing the results of each week. The authors of the article used a mixed methodology combining both quantitative and qualitative methods of analysis. In particular, participants filled out questionnaires before and after completing the course, which made it possible to track changes in their self-esteem, knowledge of the theoretical foundations of STEM, as well as in their approaches to compiling educational materials. Statistical methods, including the Wilcoxon t-test and the W-test, as well as Likert scale analysis, were used for quantitative analysis. 80 lesson plans compiled by the course participants were studied, which made it possible to trace the degree of integration of STEM components into pedagogical practice. The results showed a significant increase in the level of self-efficacy of future teachers, especially in aspects related to confidence in using STEM methods and the ability to integrate various disciplines - natural sciences, technology, engineering and mathematics - into a single educational process. The role of natural sciences and mathematics was particularly appreciated, but technology, despite its importance, received less pronounced support. It is important to note that the teachers not only demonstrated an increase in knowledge, but also began to see the connection between theory and practice, which manifested itself in their lesson plans and project assignments. According to the majority of participants, the course was useful, interesting and significantly expanded their pedagogical horizons. However, the study had its limitations. It was conducted over the course of one semester and without the participation of a control group, which reduces its internal reliability. In addition, video materials proved to be less effective than face-to-face demonstrations, which underscores the importance of personal interaction in the training of future teachers. Despite this, the results of the study confirm the value of the proposed format and design of the course, and also emphasize the need to include integrated, interdisciplinary and practice-oriented approaches in the teacher training system. The authors conclude that for the successful implementation of STEM education in practice, it is necessary not only to teach individual topics, but to form a full-fledged system to support the professional growth of teachers. This includes the exchange of experience, the joint development of materials, the development of new technologies and the formation of an educational community in which teachers feel confident and motivated. Such courses can become the basis for the further development of STEM education and the formation of a new generation of teachers capable of inspiring students to interdisciplinary thinking and research activities.

The article by Devi Wisudawan (2022), titled *"The Effect of Integrated Chemistry Practice Learning Implementation on Student Learning Outcomes,"* presents a practical and timely investigation into how integrated chemistry lab work can enhance students' academic success. The study was conducted with 10th-grade vocational high school students in Indonesia and explores how combining hands-on laboratory experiments directly into regular classroom lessons affects their learning outcomes in chemistry.

The author starts by addressing a common challenge in chemistry education: students often struggle with understanding abstract concepts, especially when theory and practice are taught separately. In many schools, practical activities are scheduled long after the theory has been taught, often outside normal class hours. This delay creates a gap in learning - by the time students get to the lab, they've already forgotten key concepts, making the experiment less meaningful.

To solve this problem, the study introduces an "integrated practicum" approach, where theory and lab work are taught together in a seamless flow. Instead of learning the content first and doing the practical work later, students get immediate hands-on experience as they learn new material. This method helps them not only understand the content better but also develop key scientific skills like observation, hypothesis building, data analysis, and communication.

The research design was quasi-experimental, involving 58 randomly selected students divided into an experimental group (who received integrated practicum lessons) and a control group (who were taught using raditional cooperative methods). Both groups were tested before and after the lessons to compare progress.

Results showed a clear advantage for the integrated group. While both groups started at similar levels (around 60 points on the pre-test), the experimental group improved significantly more by the end of the study, with an average post-test score of 72.83 compared to 64.10 in the control group. This 4.95% increase in achievement was statistically significant, supported by a t-value of 5.149 - well above the threshold for significance.

In discussing the findings, the author points out that integrated practice doesn’t just help students perform better academically - it also encourages them to engage more deeply with the material and become more confident using scientific equipment. That said, the study also acknowledges some limitations: when the practical activities are too spread out or disconnected from the lesson content, the benefits weaken. Therefore, careful timing and planning are essential to make this method truly effective.

In conclusion, Wisudawan’s research strongly supports the idea that integrating practical activities directly into chemistry lessons helps students learn more effectively. This approach aligns well with modern STEM education goals, emphasizing real-world application, critical thinking, and active learning. It’s a valuable resource for educators aiming to improve student outcomes and make science more engaging and relevant in the classroom. (Wisudawan, 2022)

1.4 Creating integrative lesson plan in chemistry

In the article from 2012 *“Considerations for Teaching Integrated STEM Education,”* Stohlmann, Moore, and Roehrig explore what it truly takes for teachers to implement integrated STEM instruction effectively. Drawing on a year-long collaboration with a middle school using the *Project Lead The Way* (PLTW) curriculum, the authors present a practical framework known as the s.t.e.m. model, which focuses on four key areas: Support, Teaching, Efficacy, and Materials.

The main goal of the study was to identify what kinds of knowledge, experience, and resources teachers need to feel confident and competent in teaching STEM in a way that blends subjects together. The researchers found that while integrated STEM education offers clear benefits-like encouraging critical thinking, problem-solving, and collaboration among students-many teachers face challenges when stepping outside their traditional subject areas.

One of the biggest takeaways is that teacher confidence and support are crucial. The study showed that when teachers had regular opportunities for collaboration, professional development, and access to hands-on materials, they felt more prepared and willing to try interdisciplinary teaching approaches. On the flip side, uncertainty about curriculum structure or a lack of content knowledge in engineering or math, for example, often made teachers hesitant.

Importantly, the study also highlights how student-centered learning-through projects like building dragsters or Rube Goldberg machines-can boost engagement and help students better connect concepts across science, math, and technology. The researchers argue that with the right support systems in place, integrated STEM can make learning more meaningful and connected to the real world.

Ultimately, this article provides both practical and research-based insights that are valuable for schools, administrators, and educators looking to adopt or improve STEM programs. The s.t.e.m. model offers a grounded starting point for thinking about what successful STEM integration really involves-not just in theory, but in everyday classroom practice. (Stohlmann et al., 2012)

“Sample Integrated Lesson Plan: Sensory Perception and the Role of the Maillard Reaction in the Flavor Development of Chocolate” (Florida Department of Education, 2013)

This lesson plan is a creative and engaging example of interdisciplinary teaching, merging chemistry, biology, and culinary arts into one seamless learning experience. Developed as part of the "Culinary Arts 1" course, the 60-minute session introduces high school students to the science behind flavor - specifically, the chemistry of the Maillard reaction, a process that plays a vital role in the taste, aroma, and color of chocolate and many other foods.

The lesson centers around the question: *What makes food taste the way it does?* Students explore how sugars and amino acids interact under heat, producing the complex flavor compounds we associate with roasted, browned, and cooked foods. Through interactive projects like vertical chocolate tasting and demonstrations of cocoa bean roasting, students will have the opportunity to use all of their senses and tie the scientific theory to a lived experience.

Even beyond the science of taste, the lesson helps students see the factors such as sensory input, food chemistry, and cultural preferences that affect the way we sense flavor. Students will complete vocabulary exercises, assess the texture and smell of various chocolates, categorize terms and their definitions, and reflect on how variables such as color, temperature, and memory influence the merit of same flavor.

The most exciting thing about this lesson is the authentic experience. Students are not just learning chemical equations to memorize; they are now connecting chemistry with a real and delicious application of their knowledge – chocolate. This conveys memory-making learning, and meaning-making learning.

They also discuss the darker side of the Maillard reaction, such as the formation of potentially harmful compounds like acrylamide in overcooked or processed foods, adding a layer of critical thinking and health awareness to the science lesson.

The lesson concludes with small group discussions and a reflection activity, where students consider how the complexity of this reaction provides chefs with a wide range of creative opportunities - a brilliant way to show that chemistry can be as much an art as it is a science.

In essence, this integrated lesson plan demonstrates the power of interdisciplinary education. It brings chemistry to life through food, deepens understanding of scientific processes, and shows students how science, culture, and daily experience are all interconnected. It’s a prime example of how integrative STEM education can make learning both rigorous and relevant. (Florida Department of Education, 2013)

"Effects of Technology-Integrated Chemistry Instruction on Students’ Academic Achievement and Retention Capacity"

This study, published in the *Journal of Education and Learning* in 2023, explores how integrating technology into chemistry teaching impacts students' academic achievement and their ability to retain knowledge. Set in Ethiopian secondary schools, the research focuses particularly on the challenging topic of chemical bonding - a subject students often struggle with due to its abstract and microscopic nature.

The authors used a rigorous Solomon four-group quasi-experimental design, which is notable because it controls for many biases common in educational research. This design involved two experimental groups that received technology-integrated instruction and two control groups that followed the traditional "chalk-and-talk" method. The implementation of technology tools such as interactive animations, simulations, and computer-based models was designed specifically to provide students with visual representations of complex chemical ideas.

The results were phenomenal. Students who were taught using technology experienced nameless gains on achievement tests initiated right after the instruction and the students retained more information four weeks later, when compared to other groups taught using a traditional approach. Specifically, tests of statistical significance were completed using a statistical analysis of variance (ANOVA) and a t-test, which indicated a significant difference existed between the experimental and control groups, regarding both the achievement score and retention score. Their study also found no statistically significant differences existed between male and female students in terms of achievement and retention, thus the authors concluded technology infusion provided equitable learning opportunities for all students.

For many critical reasons, this study did more than just conclude there’s promise in using technology; there are long-term, pedagogical reasons for finding the tools. The study also detailed discussions about making chemistry ideas more relatable and comfortable. The authors noted that most traditional current pedagogies do not allow students to make connections with the microscopic reality of atoms and molecules, thus providing confusion upon completion of activity and poor results. The study suggested technology provided not just visualizations, but multisensory usage of videos, simulations, use of modern technology, interactivity, etc. The authors provided convincing evidence that technology provides an opportunity to enhance students' understanding of chemistry and retention of information because it provides a complete range of varied learning opportunities.

And on a larger scale that reinforces the premise teachers will not be relegated to always teaching in a traditional didactic manner. If educators are going to improve science education, and more so in an abstract area such as chemistry, pre-service and in-service teachers must embrace technology then implement it and make it part of their work in the classroom explicitly. Teacher education programs should also develop more classes for in-service teachers that give teachers ideas and training around using these technologies.

Overall, this research provides strong, empirical evidence that technology-integrated instruction can significantly enhance learning in chemistry, making abstract concepts tangible and improving both immediate understanding and long-term retention of complex scientific knowledge. (Yesgat et al., 2023)

"Reviewing Assessment of Student Learning in Interdisciplinary STEM Education"

This paper presents a comprehensive and much-needed review of how student learning has been assessed in interdisciplinary STEM education over the past two decades. As STEM education gains more attention globally, understanding how to effectively assess integrated, interdisciplinary learning becomes increasingly important - and yet remains a major challenge.

The study systematically analyzed 49 empirical research articles selected from an initial pool of 635 studies. To structure their review, the authors developed a two-dimensional framework. The first dimension focused on the nature of the disciplines involved in the assessment (monodisciplinary, interdisciplinary, and transdisciplinary), and the second dimension addressed the learning objectives targeted (knowledge, skills, practice, and affective domains).

Key Findings: The review revealed that, despite the intention of many STEM programs to promote interdisciplinary learning, most assessments still focused mainly on monodisciplinary knowledge (such as just science or math individually) and on affective outcomes (such as student interest and motivation). Very few studies genuinely assessed interdisciplinary understanding or interdisciplinary practices. In particular, assessments of complex skills - like engineering design thinking or interdisciplinary problem-solving - were rare.

The article also highlights significant inconsistencies: while many programs claimed to promote interdisciplinary STEM learning, their actual assessment methods did not align with these goals. In practice, evaluations remained largely discipline-specific and traditional, relying heavily on multiple-choice tests and self-report surveys rather than truly measuring cross-disciplinary reasoning or design skills.

Novelty and Importance: What makes this work particularly valuable is that it doesn’t just review past studies - it also points out critical blind spots in current STEM assessment practices. The novelty lies in the proposed two-dimensional framework for categorizing STEM assessments, offering a clear and structured way for researchers and practitioners to think about how assessments should be designed to capture the true spirit of interdisciplinary learning.

The paper also emphasizes the urgent need for more practical, classroom-friendly assessment tools. It argues that current methods, often research-focused and resource-intensive (like video coding and complex rubrics), are not suitable for everyday teaching environments. Therefore, it calls for developing simpler, scalable tools that teachers can realistically use to assess STEM learning processes and outcomes over time, not just snapshots of content knowledge.

Conclusion: Overall, the review concludes that although the field of interdisciplinary STEM education is growing, there is a mismatch between what STEM programs aim to achieve and what they actually assess. If STEM education is truly to prepare students for solving real-world problems, future research and practice must prioritize creating assessments that genuinely capture interdisciplinary skills, practices, and deeper learning - not just isolated knowledge of individual subjects. (Gao et al., 2020)

Aaron Rohde’s study *"Assessment and Engagement Strategies for STEM"* offers a sincere, practice-driven exploration of how assessment methods and project-based learning influence student engagement in STEM education. Set in a real-world 5th-grade classroom in rural Nebraska, this research captures the everyday realities of teaching, where enthusiasm, curiosity, and real learning are often hard-won victories. Rohde approaches the topic not just as a researcher, but as a deeply reflective teacher who genuinely wants to find better ways to reach and inspire his students.

At its core, this study was built around an important question: does the type of assessment strategy used in STEM lessons - whether a traditional test, a creative poster project, or a collaborative group activity - influence how engaged students are? To explore this, Rohde conducted action research throughout an entire semester, combining student interviews, teacher journals, surveys, and artifacts of student work. What he discovered was enlightening: it wasn't the type of assessment that made students more engaged - it was the very presence of STEM projects themselves that transformed the learning environment.

Across multiple projects, from building balloon-powered cars to designing food webs, students consistently showed higher levels of enthusiasm, independence, and creative thinking. They were more willing to explore ideas, solve problems on their own, and collaborate with their peers. The introduction of STEM projects shifted students' mindsets from passive recipients of information to active creators of knowledge. Even students who previously relied heavily on the teacher for guidance started searching for information independently, discussing strategies with their classmates, and taking genuine pride in their work.

Interestingly, while assessment strategies like tests, posters, and peer-reviewed projects were announced ahead of time, they did not significantly alter students' engagement levels. Instead, the most powerful factor was the nature of the projects themselves - hands-on, real-world, and meaningful. Rohde noted that students were far more motivated when the learning experience felt authentic and connected to real-life challenges, rather than framed solely as preparation for a test.

Another important theme that emerged from the study was the critical role of feedback. Early in the research, many students associated feedback simply with grades or scores. However, as they engaged more deeply with STEM projects, their understanding evolved. By the end of the study, students emphasized the value of feedback that helped them improve, rethink, and refine their work - a clear indicator of their growing ownership over the learning process.

Rohde's work is especially valuable because of its human authenticity. This is not a case study that is removed from reality - this is a living, breathing description of how real students respond to real challenges. She refers to, and illustrates, the fact that authentic student engagement does not just happen. It exists because we take the time to develop and nurture meaningful learning opportunities that allow students to think critically, make connections in their learning, engage collaborative and personally in their work.

The most significant contribution of the study in terms of originality is the glaring notion that engagement really happens not because of prescriptive assessment practices but because of the ways in which and opportunities that students have to merge learning with artistic creativity, exploration, and application to authentic contexts. Rohde’s work makes a clear demand of educators to better define our priorities: to consider how we can create classrooms that put value more on exploration than memorization; collaboration rather than isolation; and on personal growth rather than judgment of progress.

In conclusion, *"Assessment and Engagement Strategies for STEM"* is a powerful reminder that students are capable of extraordinary things when given the right environment. STEM projects, when thoughtfully integrated into the curriculum, can ignite a passion for learning that traditional methods often struggle to achieve. Aaron Rohde’s reflections provide not only practical insights for educators but also a heartfelt affirmation of why innovative, student-centered teaching matters so deeply today. (Rohde, 2019)

The article *"Teaching and Assessment Methods: STEM Teachers’ Perceptions and Implementation"* by Akiri, Matathia Tor, and Dori (2021) presents a comprehensive investigation into the instructional and assessment practices employed by STEM teachers in Israeli schools. The study is notable for its empirical depth, involving a large-scale survey of 125 STEM teachers and subject coordinators across primary, middle, and high school levels.

The primary aim of this research study was to examine both the preferred and used teaching and assessment methods in STEM learning, and the extent to which factors like teaching experience, subject area, type of school and cultural context influenced the use of methods in STEM education. Although it is widely recognized and suggested that student-centered, inquiry-based methods should be used in STEM education, the results show that traditional teacher-centered methods continue to be used. Lecturing and structured, guided presentations continue to be the most commonly used teaching methods and traditional written assessments, predominantly tests of open- and closed-ended questions continue to be the predominant methods used to assess learner performance.

The research study also identified a significant difference between the types of practices preferred by the subject coordinators and the practices actually used by regular teachers. Coordinators were more inclined to recommend group-based and alternative assessment practices like report writing from experiments and project portfolios. The ways in which systemic factors, like being required to prepare students for standardized tests or lack of class time, not enough teaching and learning resources, and limited opportunities for professional development prevented teachers from using those types of practices.

One of the contributions of the study is that it was able to discriminate between the context variables that inform teachers' instructional practices. For example, science teachers used inquiry-based and experimental techniques somewhat more than did mathematics teachers. In addition, experienced teachers used colloborative and experiential learning practices more than novice teachers. Finally, there was evidence to indicate that teachers from minority schools used more structured group learning activities that followed the community's emphasis of discipline and authority.

Overall, there was a novelty to this research as it systematically compared all the teaching (14 different methods) and assessment (8 different methods) strategies used in the STEM context, as a means to provide layers of information to make sense of teacher practices in STEM classrooms. A important take away message was that for educational change in STEM (and general learning) to be achieved will require more than recommendations for improved policy , but will require schools to adequately provide support, training and conditions to allow teachers to use innovative methods with a realistic sense of being held academically accountable.

In conclusion, Akiri et al. (2021) has maintained there continues to be institutional constraints and contextual realities for educators in STEM instruction and assessment to be capable of leading change in their practices towards more effective teaching and assessments. There needs to be a systematic approach to professional learning and assessing in order for STEM education to realize its full potential in enhancing creativity, critical thinking, and interdisciplinary problem solving capability of students. (Akiri et al. 2021)

Figure 1 reflects the composition of the academic sources used in this research study, sorted by the year of publication.

As seen in the chart, the majority of the referenced works were published in 2024, reflecting a strong emphasis on the most recent developments and research trends in STEM education. This is followed by a notable number of studies from 2021, 2023, and 2019, which collectively demonstrate a growing academic interest in the integration of technology and interdisciplinary methods in chemistry teaching over the past five years. The remaining sources, grouped under "Other," span earlier years and provide foundational insights necessary to contextualize recent advancements. This distribution ensures a balanced combination of current findings and theoretical underpinnings essential for the credibility and depth of the research.

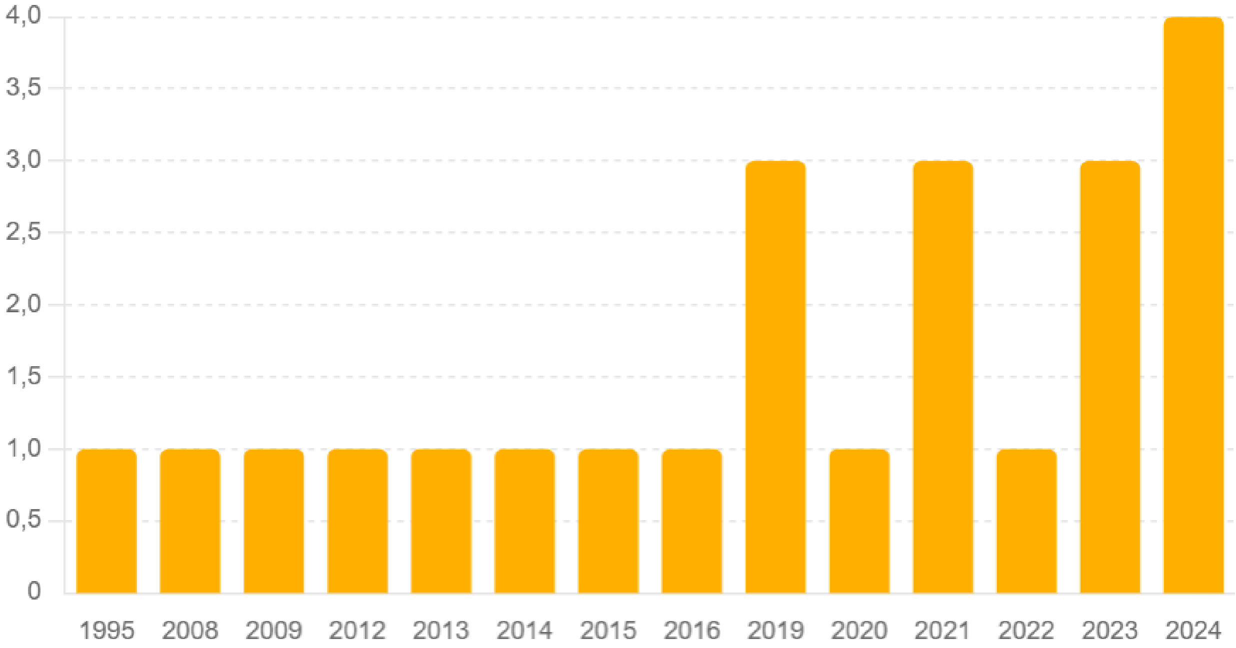


Figure 1.1 *Distribution of References by Year of Publication*

Research questions:

1. What are the key components and structure of an effective integrative STEM unit plan for 10th-grade chemistry?
2. How does the STEM unit plan influence students' conceptual understanding and problem-solving skills in selected chemistry topics?
3. What changes, if any, occur in students' engagement and academic performance after the implementation of the STEM unit plan compared to traditional instruction?

METHODOLOGY

Methodology is a fundamental part of any scientific research, determining how data will be collected, processed, and interpreted. Within the framework of this study, the methodology is aimed at obtaining objective, reliable and reproducible results regarding the effectiveness of the implementation of the STEM approach in chemistry teaching in the 10th grade. Taking into account the purpose of the work - to develop and test an integrative STEM-unit chemistry plan - the study uses an experimental approach based on a comparison of the results of students in the experimental and control groups. This choice makes it possible to establish causal relationships between the use of the STEM model and changes in the level of student academic achievement. This section includes a description of the type of study, characteristics of the participants, tools, applied methods of data analysis, as well as ethical aspects that ensure the correctness of the study. A detailed description of each component of the methodology is aimed at ensuring transparency and scientific validity of the work carried out.

2.1 Research context and setting

The research study was conducted in Almaty, the largest city of Kazakhstan Republic which is located in southeastern part, near the borders with Kyrgyzstan and China. Approximate population of Almaty is around 2 million people. And the true number is much bigger than it is, because there are a lot of cities, a lot of districts near Almaty. In recent years, the education system of Kazakhstan has been increasingly moving towards the introduction of modern educational approaches, among which special attention is paid to the integration of STEM education. However, in practice, this integration is most often implemented selectively and without proper methodological elaboration, especially in subjects of the natural science cycle, such as chemistry. This was the starting point of my research. The work was carried out on the basis of a College located in Almaty, which is typical in its conditions for most Kazakhstani educational institutions: classroom-based system, lack of a full-fledged chemical laboratory, limited logistical resources. Nevertheless, the college has a high interest in updating the content and finding new pedagogical solutions, and the administration actively supports the introduction of innovations. The choice of this particular college is not accidental - it reflects the real conditions in which most chemistry teachers in the country work. These are the institutions that need practical, flexible, and tailored STEM solutions. The study was conducted among 10th grade students, since at this age students already have the necessary level of knowledge to comprehend and apply interdisciplinary connections, including on the example of chemical concepts and processes. It is important to note that in the course of the work it was possible to observe how much students are involved in the educational process if it acquires an applied, practice-oriented character. Even despite the lack of a laboratory base, due to project tasks, visualizations, digital solutions and elementary engineering thinking, it was possible to activate the cognitive activity of students. Thus, the study was conducted in conditions close to the reality of most educational institutions in Kazakhstan, where opportunities are limited, but there is a desire for quality education and a willingness to change. This made it possible to evaluate the effectiveness of the developed integrative STEM unit plan in a live, practical context.

2.2 Design of the study

This research is applied in nature and is aimed at developing, implementing and evaluating the effectiveness of an integrative STEM chemistry unit plan for 10th grade students. To achieve these goals, a mixed research design was used, combining both elements of a qualitative and quasi-experimental quantitative approach. The study was structured in several stages:

1. The analytical and theoretical stage included the study of literature on STEM education, the analysis of chemistry curricula, pedagogical strategies and methodological approaches used in integrative learning. Special attention was paid to foreign experience and conditions close to the actual teaching practice in Kazakhstani educational institutions.
2. The design stage involved the development of a STEM unit plan based on the methodological principles of the 5E model (Engage, Explore, Explain, Refine, Evaluate), which includes tasks for all STEM components - scientific experiments, mathematical modeling, technical descriptions and engineering tasks related to the chemical topic.
3. The practical stage included the testing of the developed unit plan in real-world college-based learning conditions using two groups: a control group (trained according to the traditional methodology) and an experimental group (trained according to the STEM unit plan). Monitoring the learning process, collecting feedback from students, as well as analyzing the results of students made it possible to evaluate the effectiveness of the proposed approach.
4. The evaluative and reflective stage was aimed at understanding the data obtained, identifying the strengths and weaknesses of the implemented

methodology, as well as formulating practical recommendations for teachers on the implementation of STEM learning in chemistry teaching.

To ensure the depth and objectivity of the analysis, qualitative analysis tools were included in the study: pedagogical observation, conversations with students, as well as quantitative methods - comparing the results of the entrance and final control of both groups.

The choice of a mixed design is conditioned by the need both to develop a pedagogical product and to evaluate its real effectiveness in conditions as close as possible to a typical educational environment.

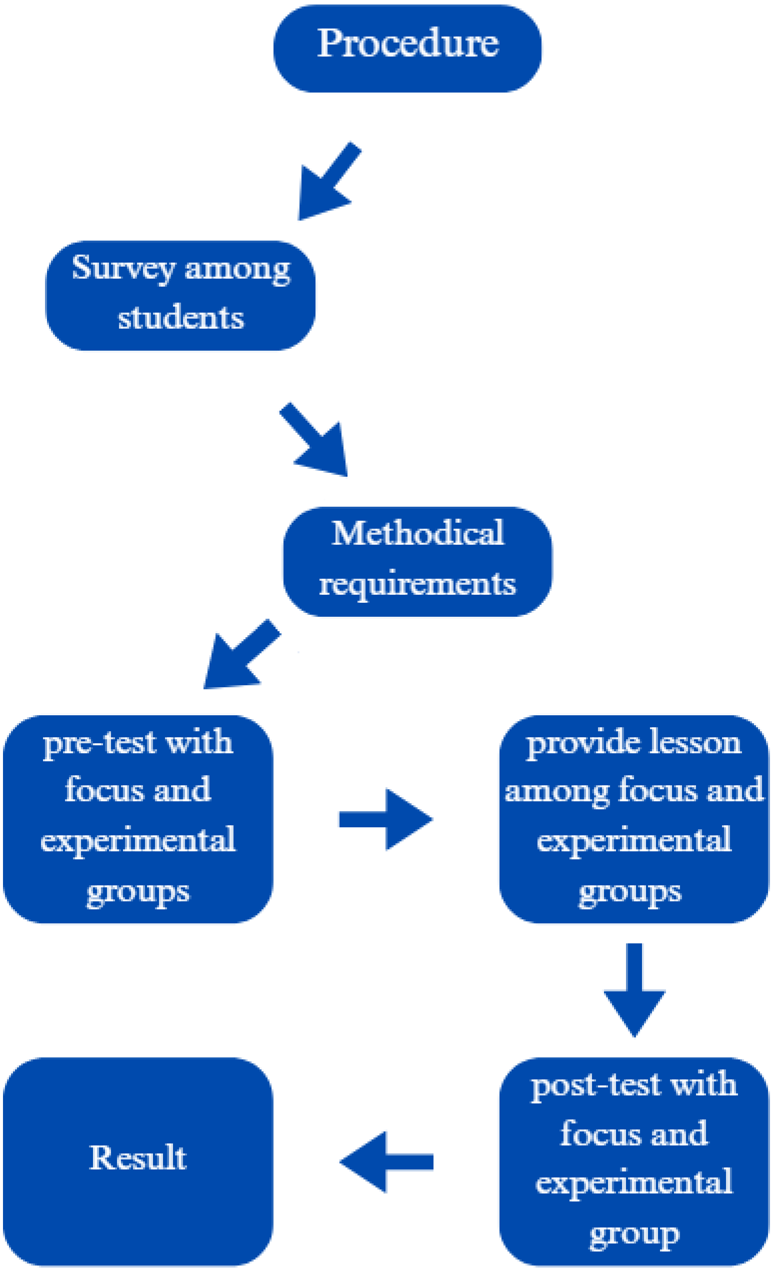


Figure 2.1 *Research procedure of the STEM lesson implementation and evaluation process*

2.3 Study sample

The study involved 10th grade students from one of the colleges of the Republic of Kazakhstan, enrolled in an educational program with in-depth study of natural sciences. A total of 46 students participated in the study, divided into two groups: experimental (23 people) and control (23 people). The groups were formed taking into account the principle of educational uniformity: both classes had previously demonstrated similar results in chemistry, which provided a more objective comparison in a pedagogical experiment. The experimental group studied according to a specially developed STEM unit plan that includes the integration of science, technology, engineering, and mathematics components into the content and structure of the "Atoms and Chemical Structures" lessons. The control group followed the same topic according to the traditional teaching methodology, without using an interdisciplinary approach and engineering tasks. The same assessment tools were used for both groups: the entrance test (pretest) and the final test (posttest), which made it possible to objectively assess the level of changes in learning outcomes. Participation in the study was voluntary, with prior information from students and their parents (legal representatives) about the objectives and content of the experiment. In addition, to ensure ethical correctness and compliance with academic standards, the principle of anonymity was observed during the research process: participants' personal data was not collected and was not used in the processing and presentation of the results.

2.4 Data collection procedure

The nature of the research is determined by its purpose and objectives, as well as the approach to data collection and analysis. This study belongs to the category of experimental pedagogical research with elements of comparative analysis, since the main goal is to test the effectiveness of the implementation of an integrative STEM-unit chemistry lesson plan in the 10th grade. The experimental approach makes it possible to establish causal relationships between the chosen teaching methodology and changes in students' academic achievements.

Before moving on to the experimental part of the study, a short preliminary survey was carried out among the participating students. Its main goal was to get a clearer picture of how students initially viewed the use of digital tools in chemistry classes-such as virtual labs, interactive simulations, and educational videos. The questions were aimed at uncovering not only their prior experience with these tools, but also their attitudes and expectations regarding such technologies in the learning process.

The survey was useful in establishing the students' overall digital literacy level as well as preconceived ideas that might influence their experience with the STEM-based curriculum. The data served as an integral starting point for making adjustments to our course design- helping to select effective tools and teaching strategies that coincided with the interests, abilities, and comfort levels of the actual learners involved in the experiment.

The questionnaire included eight statements, which students rated on a Likert scale from 1 (“totally disagree”) to 5 (“totally agree”). The intent was to identify students' understanding of interdisciplinary learning, particularly if they had engaged in multi-disciplinary projects that combined chemistry with physics, mathematics, or engineering. The questionnaire also queried students' past exposure to digital learning tools consisting of virtual laboratories, simulations, and educational applications. In addition, the questionnaire asked if students enjoyed using these tools and if they perceived the tools to be beneficial in strengthening their understanding of chemistry content. Another desire was to assess students' confidence in applying knowledge across disciplines and understanding if students would consider chemistry relevant to their own life experiences and professional futures. The survey results offered rich insight into student experience and shaped the planning of the STEM integrated lesson. We made decisions based on the questionnaire data and were able to select appropriate teaching tools and strategies to guide based on students' previous knowledge and interests- thereby creating meaningful and more comfortable learning experiences.

In particular, the study includes the creation, implementation, and evaluation of a specially designed STEM unit plan on a topic relevant to the 10th grade curriculum. The students of the experimental group studied according to this plan, while the control group studied the same topic using a traditional approach to teaching chemistry. The study includes two stages-preliminary and main. At the preliminary stage, the initial level of knowledge of both groups is diagnosed using the same test (pretest). After completing a series of lessons on the topic "Atoms and Chemical Structures" (or another selected topic), a post-test is conducted to determine the increase in knowledge and identify differences between groups. This approach is especially important for evaluating the effectiveness of innovative pedagogical solutions, as it allows us to obtain objective quantitative data that can be statistically processed and interpreted. Thus, the type of research can be characterized as mixed (quantitative + qualitative), with a predominance of a quantitative component focused on objective verification of the results of the introduction of STEM methods into the educational process in chemistry. The object of this study is the process of teaching chemistry in secondary schools, in particular, the system of organizing and conducting training sessions in the 10th grade using various pedagogical approaches. The object was chosen taking into account the relevance of the introduction of innovative methods into educational practice and the need to improve the quality of mastering chemical concepts by students. The subject of the study is the impact of the integration of the STEM approach on the learning activities of students within the framework of teaching a specific topic of a school chemistry course. In particular, the subject is changing the level of learning of educational material, increasing engagement and developing interdisciplinary skills among students using a specially developed STEM-unit lesson plan. Thus, the object covers a broad context - the educational process as an integrated system, whereas the subject is a specific aspect of this process, focusing on the content, structure and pedagogical effect of integrative STEM chemistry lessons.

The choice of this object and subject is conditioned by the need to solve the following practical tasks:

- strengthening interdisciplinary ties in school chemistry education;
- Developing students' critical and engineering thinking;
- increasing motivation to study natural science disciplines through the use of project-based and problem-oriented teaching methods.

In addition, the research is aimed at expanding the theoretical and methodological base for the development and testing of STEM-unit plans adapted to the Kazakh education system.

Thus, the choice of participants was justified by the need to obtain reliable, reproducible and comparable data as part of a pedagogical experiment aimed at analyzing the effectiveness of integrating the STEM approach into school chemistry education.

Digital technologies played a central role in bringing the STEM approach to life. During lessons, students used interactive platforms such as PhET Simulations (specifically the “Build an Atom” activity), ChemSketch, and Tinkercad. These tools helped visualize atomic structures, simulate electron configurations, and even allowed students to design simple digital projects. Other applications and 3D models were also introduced to explore the periodic table and the properties of chemical elements, making lessons more interactive and easier to understand.

Laboratory sessions were conducted using standard school chemistry equipment: test tubes, tripods, burners, measuring cylinders, scales, and common reagents like zinc, copper, hydrogen peroxide, acetic acid, and potassium permanganate. Personal protective equipment was always used to ensure safety. In engineering-focused tasks, students also worked with everyday materials-starch, glycerin, plastic parts, wires, and paper-to create models of chemical reactions, anti-corrosion coatings, and even biodegradable films.

To assess the effectiveness of the STEM unit plan, both quantitative and qualitative methods of data analysis were applied. This mixed-methods approach provided a deeper insight into how the new teaching model influenced student engagement, knowledge retention, and the development of interdisciplinary competencies.

The main quantitative tool was the results of the entrance (pretest) and final (posttest), which were conducted in both groups: experimental and control. The tests were developed in an identical structure and covered tasks for knowledge of theoretical material, the application of chemical concepts in practical situations, as well as analytical thinking and working with graphs and diagrams. The test results were processed using descriptive and comparative statistics. The average scores, median values, standard deviations, and result increments (delta progress) for each group were calculated. To statistically test hypotheses about the effectiveness of the STEM approach, parametric statistical methods were used, in particular, the Student's t-test for independent samples, as well as ANOVA (analysis of variance) if it is necessary to compare several variables. The analysis was carried out using Jamovi software, which provides clarity and high accuracy of calculations. The level of statistical significance α was assumed to be 0.05, which corresponds to generally accepted scientific standards.

In addition to quantitative methods, qualitative analysis methods were used to provide a deeper understanding of the behavioral and motivational aspects of the STEM approach. During the implementation of the unit plan, students' activity, their involvement in group and individual tasks, their ability to solve engineering problems independently, and their level of cooperation and communication were systematically monitored. In parallel, reflection questionnaires were used, in which students gave a subjective assessment of their experience of participating in STEM lessons: what was difficult, what they liked, what skills they developed and how they perceived interdisciplinary integration. The analysis of the questionnaires was carried out by the method of qualitative generalization by category, with the allocation of the most frequent and significant responses. The combination of quantitative and qualitative analysis has made it possible to achieve a high degree of validity and reliability of the results, as well as to provide a comprehensive interpretation of the impact of the integrative STEM approach on the learning process. This approach meets the modern requirements of pedagogical diagnostics and contributes to the construction of sound conclusions and practical recommendations for the further application of the STEM model in school education. Like any applied pedagogical research, this work has a number of objective limitations that must be taken into account when interpreting the results obtained and their possible extrapolation to a broader educational environment. Awareness of these limitations makes it possible to increase the scientific integrity of research and identify areas for its possible expansion and deepening in the future.

First, the limiting factor is the sample size: only 46 students from one college participated in the study, which, despite observing the principle of equivalence of groups, reduces the statistical generalizability of the results for the entire population of 10th grade students. In addition, all participants studied in a similar educational environment and with the same teacher, which, on the one hand, increases internal validity, but, on the other hand, limits the variability of pedagogical conditions and teaching styles.

Secondly, a significant limitation is the lack of a full-fledged laboratory base. Despite the fact that most of the experimental tasks were adapted to the real conditions of the classroom, the inability to conduct a number of chemical experiments using more complex equipment partially narrowed the range of practice-oriented tasks, especially in the engineering and technological components of STEM.

Thirdly, the limited research time (four weeks of active STEM training) does not allow us to fully track the long-term effects of the introduction of this technique. Although the increase in knowledge was recorded in the short term, the formation of sustainable skills in interdisciplinary thinking, project activity and critical analysis requires longer observation and subsequent tracking of dynamics.

It is also worth noting that some students may have been more motivated in advance or, conversely, had difficulty adapting to an unconventional lesson format, which could affect the results within individual subgroups. Although the teacher tried to provide the same attention and support, the factor of individual differences in the perception of the STEM approach should be taken into account when analyzing the results. Finally, possible subjectivity in the evaluation of project assignments and feedback questionnaires should be taken into account. Despite the use of clear criteria and structured assessment tools, some interpretation remains in the analysis of qualitative data, which is a typical feature of humanitarian and pedagogical research. Thus, despite the indicated limitations, the research remains a significant and justified step towards the introduction of a STEM approach in chemistry teaching. These limitations should be considered as growth points for future studies involving a wider sample, long-term follow-up, and expanded experimental conditions. The methodological basis of this study was built in accordance with the goals and objectives aimed at evaluating the effectiveness of integrating the STEM approach into chemistry teaching at the 10th grade level. The use of experimental design with the participation of control and experimental groups provided an opportunity for an objective comparison of the results obtained in traditional and STEM education. The comprehensive nature of the study, combining quantitative and qualitative methods of data analysis, allowed not only to record an increase in academic achievement, but also to better understand the motivational and behavioral changes among students caused by the use of an interdisciplinary approach. Carefully selected tools - from tests and laboratory tasks to digital simulations and engineering cases - ensured reliable diagnostics and allowed us to track the development of skills beyond the usual assimilation of chemical facts. Taking into account the real conditions of the educational environment, resource constraints and compliance with ethical principles during the experiment helped to increase the reliability of the data obtained. Thus, the methodology used in the study is a holistic, well-founded and reproducible model of pedagogical experiment that can serve as an example for further research aimed at introducing STEM education into school practice.

2.6 Data Analysis

To understand whether the integrative STEM unit plan truly made a difference in students’ learning, a mix of basic and advanced statistical tools was used. First, we looked at the descriptive statistics-things like average scores and how much they varied from student to student (measured through standard deviation). This gave us a general sense of how students performed overall and helped highlight any early patterns. To dig deeper, we used an independent samples t-test to compare the results of the control group (who followed a traditional chemistry curriculum) and the experimental group (who experienced the STEM unit plan). This test helped us see if any difference in performance between the two groups was statistically meaningful, not just random. In some cases, we needed to compare more than two groups or factors-so we turned to ANOVA (Analysis of Variance) to analyze those variations. And because the study also looked at more than one outcome at a time-like content knowledge and interdisciplinary skills-we used MANOVA (Multivariate Analysis of Variance) to see how the intervention affected multiple areas together. Altogether, these tools helped paint a clearer picture of what worked, for whom, and to what extent, giving us a solid foundation to evaluate the impact of the STEM approach on students’ learning experiences. As an example table 2.6.1 is given

Table 2.6.1 *Scale Reliability Statistics for the STEM Participation Questionnaire*

	Mean	SD	Cronbach's α	McDonald's ω
scale	2.77	0.649	0.759	0.763

RESULTS

3.1 Key components and structure of an effective integrative STEM unit plan

To answer the first research question - "What key components and structure make the STEM unit plan really effective?"-a methodological program was developed based on four topics from the school chemistry course: "Atoms and chemical structures", " Introduction to organic chemistry", "Rate of reaction" and "Redox reactions".

Each of the topics was not just explained, but immersed in the context of real life and other subject areas. The plan was designed to focus on one of the STEM components every week. During the science week, students conducted experiments, observed, drew conclusions-in general, they felt like real researchers. Digital tools were actively used in the technology week-virtual laboratories, simulators, and programs for modeling molecules, which made the lessons interactive and visual. During the engineering week, the students solved practical tasks-they developed their own projects, created models, for example, an anti-rust coating or a biodegradable film. And the math week helped consolidate knowledge through calculations, analysis, and working with formulas-without dry theory, just what you really need to understand.

The research procedure covers the full cycle of developing, implementing, and evaluating the effectiveness of the STEM Unit plan, which includes four chemistry topics for 10th grade. The study was conducted in natural conditions of the educational process for five weeks, including preparatory, experimental and final stages.

1. Preparatory stage

At the preparatory stage, four school chemistry course topics with high potential for interdisciplinary integration using the STEM model were selected:

1. Atoms and Chemical Structures
2. Types of Chemical Bonds
3. Chemical Reactions and Equations
4. Redox Reactions

Separate STEM lessons with project assignments, problem situations, engineering cases, and digital tools were developed for each topic. The training was based on the 5E model (Engage, Explore, Explain, Refine, Evaluate), which promotes the formation of analytical and critical thinking among students.

The following were also prepared:

- entrance and final test (pretest and posttest);
- instructions for engineering mini-projects;
- tables of evaluation criteria;
- templates for self-analysis and reflection of students.

2. The experimental stage

The experiment lasted 5 weeks, one week for each topic of the STEM unit, as well as an additional week for post and pre-tests. In total, each group took 1 lesson lasting 80 minutes each week.:

- Week 1 - Atoms and Chemical Structures

Students created models of atoms, visualized electron clouds, and compared the structure of the elements according to the periodic table. Digital simulations and graphic editors were used.

- Week 2 - Types of Chemical Bonds

Workshops on modeling and forecasting chemical bond types were organized. Knowledge about the physical properties of substances was integrated, and connections were built between the structure and function of substances in technology and everyday life.

- Week 3 - Chemical Reactions and Equations

Students solved engineering problems, selected conditions for reactions to occur at the right speed, developed mock-ups of "reaction systems", and analyzed real industrial processes (fertilizers, metallurgy).

- Week 4 - Redox Reactions

The focus was on mathematical calculations, balancing equations, and the use of redox processes in energy and metallurgy. The students worked with redox chains and created mini-projects explaining the use of such reactions in real systems.

The experimental group implemented this STEM approach in full, including independent research, project assignments, and group reflection. The control group studied the same topics, but in the traditional way - through explaining theory, performing standard laboratory and written work.

Throughout the entire period, the learning process was constantly monitored, the levels of engagement, independence and the quality of tasks were recorded.

3. The final stage

After completing the entire cycle of topics, the students of both groups passed the final test (posttest). They were also collected:

- Students' written papers and project products;
- Feedback from participants;

The data obtained was used for quantitative and qualitative analysis, presented in the next section.

In the course of this pedagogical study, various teaching tools and materials were applied to support the implementation of an integrative STEM unit plan and to ensure that the data collected was both accurate and meaningful. When selecting these tools, particular attention was paid to the age and learning needs of 10th-grade students, the nature of the chemistry topics being taught, and the broader goal of developing interdisciplinary skills.

The main teaching resource was the author’s STEM unit plan, which was structured around four key topics: “Atoms and Chemical Structures,” “Types of Chemical Bonds,” “Chemical Reactions and Equations,” and “Redox Reactions.” Each topic was supported by carefully prepared materials-worksheets, group and individual tasks, tables, diagrams, and visual aids-designed to encourage scientific thinking and help students better analyze chemical processes.

In order to explain the process of experiment, unit plan is made:

Table 3.1.1 *Key components of Unit plan*

Topic	Method	Learning Objective	Assessment Method	Technology Used	Real-world Application
Atoms and Chemical Structures	5E model, cooperative learning	Understand atomic models and bonding	Quiz, concept mapping	PhET simulation, ChemSketch Projector	Understanding the difference between structure of organic molecules
Rate of chemical reaction	Experiment, inquiry-based learning	Analyze factors affecting reaction rate	Lab report, quiz	Stopwatch apps, Google Forms Projector	Making an mini-reactor that produces CO2
Introduction to organic chemistry	Project-based learning	Identify functional groups in organic compounds	Presentation, peer assessment, quiz	Online molecular editors Projector	Understanding Soap production and how can students make if more profitable
Redox Reactions	Simulation, modeling, water filtration	Describe oxidation-reduction processes	Model analysis, worksheet, quiz	Tinkercad, simulation tools Projector	Batteries, corrosion prevention

During the implementation of the chemistry plan developed by the STEM unit for the 10th grade, four thematic lessons were conducted, each of which focused on integrating the scientific approach with the components of technology, engineering and mathematics. Each lesson was accompanied by active student activity aimed at developing critical thinking, research skills and practical application of theoretical knowledge. This unit plan has become not just a theoretical answer to a research question, but a real model that can be applied in practice in teaching chemistry in the 10th grade.

Table 3.1.2 *Key components. Atoms and Chemical Structures*

Topic	**Method**	**Learning Objective**	**Assessment Method**	**Technology Used**	**Real-world Application**
Radioactivity	5E model, storytelling, simulation	Understand types and properties of radioactive decay	Quiz, scenario analysis	PhET simulations, video demonstrations	Radiation in medicine and energy industry
Nuclear reactions	Problem-based learning, group discussion	Explain fission and fusion processes	Project work, oral presentation	Online nuclear simulators, Projector	Nuclear power plants, atomic bombs
Energy Levels and Sublevels	Interactive lecture, digital modeling	Understand arrangement of electrons in atoms	Worksheet, digital quiz	Atomic orbit simulation tools, Projector	LED technology, spectrometry
Quantum Numbers and Atomic Orbitals	Visualization, 3D models, guided inquiry	Identify and describe quantum numbers	Quiz, concept map	ChemSketch, 3D orbital viewers	Electron configuration in modern materials

Topic 1 was devoted to the topic "Atoms and Chemical Structures". The main emphasis was placed on the formation of students' holistic understanding of the structure of the atom, starting with the historical models of Dalton, Thomson and Rutherford and ending with the modern quantum model. As part of the science block, students analyzed subatomic particles, learned how to determine the nuclear charge, mass number, isotopes, and electronic configuration. Using online PhET simulations, as well as ChemSketch and Tinkercad programs, students created virtual models of atoms and ions, visualizing orbitals and energy levels. The engineering component of the lesson was related to the analysis of the real application of knowledge about the structure of atoms in materials science and nanotechnology: students conducted a study of the properties of copper, iron and silicon, explaining how the structure of atoms affects the technical characteristics of these materials. In the mathematical part, calculations of the relative atomic mass, the distribution of electrons by levels, as well as quantitative patterns in the periodic table were considered. The students performed tasks on calculating mass fractions, analyzed periodic trends and carried out logical reasoning based on data on chemical elements.

Table 3.1.3 *Key components Rate of chemical reaction*

Topic	Method	Learning Objective	Assessment Method	Technology Used	Real-world Application
Effect of concentration on the rate of chemical reactions	Experiment, inquiry-based learning	Investigate how concentration affects reaction rate	Lab report, group discussion	Stopwatch apps, sensors, projector	Explaining industrial chemical processes
Effect of temperature on the rate of chemical reactions	Simulation, laboratory work	Determine how temperature influences chemical reactions	Worksheet, oral questioning	Digital thermometer, simulation software	Cooking, metallurgy, engine combustion
Catalysis	Demonstration, modeling	Explain the role of catalysts in reactions	Concept map, short quiz	Videos, animations, projector	Car catalytic converters, enzyme reactions
Solving problems on the topic: "Van't Hoff rule"	Problem-solving method	Apply the Van't Hoff rule to calculate temperature effect	Solving calculation tasks	Calculator, whiteboard, formulas on screen	Predicting reaction rate changes in production processes

Topic 2 focused on the topic "Rate of Reaction". In the first week, students studied the scientific foundations of chemical kinetics, including determining the average reaction rate, the effects of concentration, temperature, surface area, and catalysts. In the second week, demonstration experiments involving acids and metals (HCl reaction with magnesium, decomposition of hydrogen peroxide with a catalyst) were used for practical development of the topic, which made it possible to visually trace the influence of various factors on the reaction rate. The central part of the third week was the execution of an engineering project: students independently developed and assembled prototypes of reactors for conducting a reaction between acetic acid and baking soda in order to maximize the release of co_2 in 30 seconds. Various vessel designs were tested, temperature, tightness, and reagent ratio were varied. The result was a comparison of the amount of gas released, the reaction rate and the efficiency of the structure. The process included experimental testing, comparative analysis and subsequent optimization of the model, which contributed to the development of engineering and analytical thinking. In the mathematical part, students solved problems to predict the effect of concentration and temperature on the reaction rate, as well as to explain the action of the catalyst in terms of activation energy.

Table 3.1.4 *Key components Introduction to organic chemistry*

Topic	Method	Learning Objective	Assessment Method	Technology Used	Real-world Application
Types of formulas used in organic chemistry	Lecture, visual aids	Identify and differentiate molecular, structural, and empirical formulas	Worksheet, concept map	Projector, printed materials	Understanding chemical labeling and notation in pharmaceuticals
Composition and structure of organic compounds. Isomerism	Model building, cooperative learning	Understand structural isomers and molecular structure	Quiz, model assessment	Molecular model kits, PhET simulation	Designing isomer-based drug compounds
Classification of organic compounds	Group discussion, concept sorting	Classify organic compounds by functional group	Peer review, flashcards	Interactive diagrams, projector	Material identification in cosmetics and food industry
Nomenclature of organic compounds	Drill and practice, online editor	Name compounds using IUPAC system	Naming exercises, quiz	ChemSketch, online molecular editor	Ensuring correct naming in drug design and documentation
Nomenclature and isomerism of alkanes	Problem-based learning	Explain structural differences and naming rules	Pair assignment, game-based quiz	Tinkercad, simulation editors	Application in fuel industry and petrochemistry
Chemical properties of alkanes	Demonstration, experiment	Understand combustion and substitution reactions	Lab report, oral discussion	Stopwatch, thermometer, simulation tools	Fire safety and industrial combustion control

Topic 3 was aimed at exploring the topic of "Redox Reactions". The students defined the processes of oxidation and reduction using the concept of changing the degree of oxidation, and learned how to identify oxidants and reducing agents. As part of a laboratory experiment, students observed the deposition of copper on an iron nail when immersed in a solution of $CUSO_4$, which made it possible to visually trace the electron transfer and the change in the degree of oxidation. Additional experiments were also conducted using potassium permanganate, hydrogen peroxide, and silver, which allowed students to expand their understanding of redox processes in domestic and industrial environments. The engineering part of the lesson was presented by a project to purify water from zinc ions by electrolysis. The students assembled a model of an electrolytic installation, explained the processes at the anode and cathode, conducted a demonstration, analyzed the release of gases and metal deposition. The integration of technology, engineering, and mathematics components has provided a multifaceted understanding of processes.: Calculations based on Faraday's law were performed, the number of electrons involved in the reactions was determined, and it was explained why graphite is useful as an electrode. Through the analysis of such engineering solutions, students came to understand the importance of redox processes in energy, ecology and metallurgy.

Table 3.1.5 *Key components Redox reactions*

Topic	Method	Learning Objective	Assessment Method	Technology Used	Real-world Application
Types of redox reactions	Problem-solving, graphic organizer	Distinguish between different types of redox reactions	Written analysis, quiz	Chemix.org, interactive diagrams	Wastewater treatment, combustion analysis
Galvanic cells	Model construction, group investigation	Explain the functioning of galvanic cells and their components	Poster presentation, peer review	Circuit simulation software, voltmeters	Battery development, portable electronics
Chemical processes occurring in accumulators	Case study analysis, collaborative research	Describe chemical changes in rechargeable batteries	Short essay, infographic	Battery simulator, animated videos	Phone and EV battery life management
Electrolysis	Demonstration, guided inquiry	Understand the principles of electrolysis and electrode reactions	Oral questioning, labeled diagram tasks	Virtual lab tools, electrodes setup	Electroplating, chlorine production
Electrolysis of melts and solutions	Experimental lab, concept-based teaching	Compare electrolysis of melts versus aqueous solutions	Lab report, MCQ test	Microscale electrolysis kits, sensors	Metal refining, industrial salt electrolysis

Finally, topic 4 was devoted to the topic "Introduction to Organic Chemistry". In the scientific part, students got acquainted with the unique properties of carbon, types of organic compounds, functional groups and types of isomerism. The main classes of organic substances and types of reactions — substitution, addition, polymerization - were considered. In the technological part of the lesson, 3D modeling software was used to visualize molecules of methane, ethylene, benzene and other substances. Students used mobile applications to analyze the chemical composition of household substances, identifying functional groups. The engineering component was implemented through a practical task — the creation of bioplastics from starch, vinegar and glycerin. The students prepared the mixture, heated it to a gel, spread it on baking paper and left it to dry. In the next lesson, they tested the resulting biofilm for flexibility, strength, and water solubility. Thus, the possibility of creating environmentally friendly materials was demonstrated, which aroused students' sincere interest and desire to continue experimenting. The mathematical module included tasks on the mass fraction of elements, calculation of product yield, molecular weight of polymer and analysis of chemical equations of combustion reaction.

Thus, each of the four STEM-based lessons not only provided an in-depth understanding of key chemical concepts, but also contributed to the development of interdisciplinary skills, research activity, and orientation towards real engineering and technological challenges. The lessons demonstrated the effectiveness of an integrative approach in teaching chemistry and confirmed its importance for the formation of modern scientific thinking and practical readiness for the challenges of the 21st century among schoolchildren.

3.2 STEM unit plan influence students’ conceptual understanding and skills

To explore how the STEM unit plan influences students' conceptual understanding and problem-solving skills in selected chemistry topics, the study began by taking a closer look at where the students were starting from. One of the first steps was a short survey designed to get a feel for their prior knowledge and attitudes. The goal was to understand how familiar they were with using digital tools in learning-things like virtual labs or interactive apps-and whether they had any experience connecting chemistry with other subjects like math, physics, or engineering. The survey also asked how confident they felt applying what they knew to solve real-world problems. These insights helped tailor the unit plan to better fit the students’ needs and meet them at their level. The survey was conducted among two categories of students: those with Russian and Kazakh language of instruction. The purpose of the survey was to find out students' perception of various aspects of the STEM approach, their attitude to interdisciplinary communication, the use of digital technologies, engineering tasks, as well as teamwork in chemistry lessons.

The average response values for each position are shown in the table. Below is a detailed analysis of the data obtained.

1. The use of mathematics in chemistry

    - Russian group: 2.9
    - Kazakh group: 3.7

This indicator reflects the level of students' perception of the connection between mathematics and chemistry. In the Kazakh group, the score is significantly higher, which may indicate a greater willingness to work with quantitative data, calculations and formulas. The Russian group evaluates this component more cautiously, which may indicate difficulties in solving problems that require mathematical thinking.

2. The use of physical knowledge in chemistry

    - Russian group: 2.9
    - Kazakh group: 3.0

Both groups demonstrate an average level of agreement that chemistry lessons within the STEM unit contributed to the application of knowledge in physics. This may be due to the fact that not all topics directly addressed physical principles, but students could see cross-links in the assignments on energy, heat and electrochemistry.

3. Using digital tools

    - Russian group: 2.8
    - Kazakh group: 2.8

The indicators coincide and indicate a neutral attitude of students towards digital technologies. Despite the fact that simulations (PhET) and software modeling (Tinkercad, ChemSketch) were actively used during the lessons, students could perceive these tools as unusual or technically complex. This is a signal for teachers to pay more attention to digital literacy when introducing new tools.

Table 3.2.1 *Descriptive statistics for survey among students*

	language	N	Missing	Mean	Median	SD	Minimum	Maximum
Item1	**R**	120	0	3.20	3.00	1.058	1	5
	K	57	0	3.54	3	0.888	1	5
Item 2	**R**	120	0	2.65	3.00	1.042	1	5
	K	57	0	3.12	3	1.053	1	5
Item 3	**R**	120	0	2.61	3.00	1.140	1	5
	K	57	0	2.96	3	1.052	1	5
Item 4	**R**	120	0	2.22	2.00	0.989	1	5
	K	57	0	2.61	3	0.861	1	5
Item 5	**R**	120	0	2.69	3.00	1.035	1	5
	K	57	0	3.23	3	1.018	1	5
Item 6	**R**	120	0	1.98	2.00	0.930	1	5
	K	57	0	2.84	3	1.082	1	5
Item 7	**R**	120	0	2.62	3.00	1.109	1	5
	K	57	0	3.40	3	0.979	2	5
Item 8	**R**	120	0	2.92	3.00	1.161	1	5
	K	57	0	3.18	3	0.909	1	5

4. Participation in interdisciplinary experiments
    - Russian group: 2.3
    - Kazakh group: 2.5

The grades are below average. This can be explained either by students' lack of reflection (they did not realize the interdisciplinarity), or by the fact that the practical part was not perceived as an experiment in a broad sense. In the future, it is advisable to emphasize more explicitly which disciplines are involved in each task.

5. Group work
    - Russian group: 3.2
    - Kazakh group: 3.1

Both groups noted a positive perception of teamwork. Group assignments, brainstorming sessions, and joint projects to create models and engineering solutions were perceived as an important and useful component of the lessons. This confirms the effectiveness of STEM education in the development of soft skills such as communication and collaboration. The results of the reliability analysis of the survey aimed at assessing students' perception of STEM methods showed the following values. The average value on the scale was 2.77 with a standard deviation of 0.649. This means that, on average, students tend to take a neutral position or express little involvement in using the STEM approach in chemistry lessons. The value is close to the lower limit of the scale (if, for example, it varies from 1 to 5), which may indicate that the elements of interdisciplinary integration and the application of scientific, technological, engineering and mathematical knowledge have not been widely disseminated or properly understood among schoolchildren. A standard deviation of 0.649 indicates that students' opinions vary moderately: the answers were different, but there was no significant polarization. The Kronbach reliability coefficient (α) is 0.759, and the McDonald reliability coefficient (ω) is 0.763. These values indicate a good internal consistency of the scale, that is, all the questions in the questionnaire sufficiently measure the same construct - perception or experience of participating in STEM learning.

3.3 Changes in students' engagement and academic performance after the implementation

To achieve a 23 students took part in the sample, there are no missing data. The average score was 9.35, the median was 9, which indicates a low or moderate level of basic knowledge among most students. The standard deviation is 2.33, indicating a moderate variation in the results. The minimum score is 6, the maximum is 14, which reflects that not a single student showed a high score before applying any technique.

Table 3.3.1 *Descriptive statistics of pre and post test results of control group*

	pre-test Control group	post-test Control group
N	23	23
Missing	0	0
Mean	9.35	13.2
Median	9	13
Standard deviation	2.33	2.64
Minimum	6	7
Maximum	14	19

After completing the STEM lessons course, the average score on the final test rose to 13.4 with a standard deviation of 2.64. The minimum score was 7 points, the maximum was 19, and the median value was 13, reflecting a steady increase in knowledge among most participants. The increase in the maximum value by 5 points and the median by 4 points especially highlights the overall shift towards higher academic achievement compared to the control group.

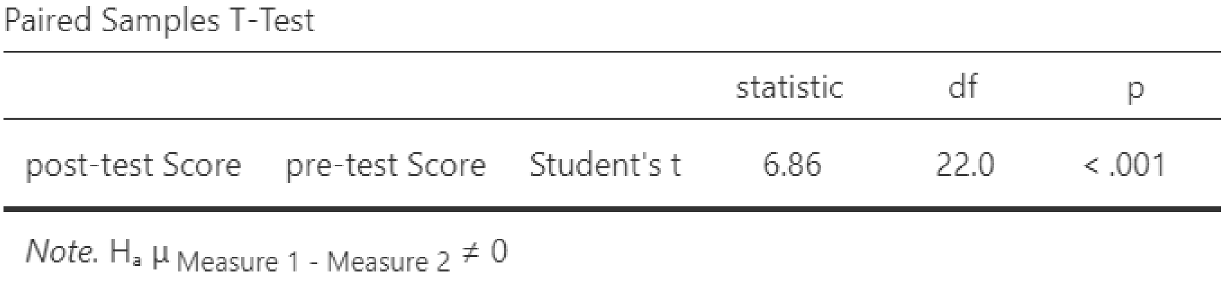
Thus, at the level of descriptive statistics, there is already a positive trend in learning outcomes after the introduction of the STEM approach.

A paired t-test was conducted to determine the statistical significance of the differences between the results of the entrance and final tests. (Table 3.2.2) The test results are as follows:

- **t = 6.86**
- **df = 22**
- **p < 0.001**

The results of the paired t-test conducted for the control group showed a statistically significant improvement in results after traditional training: t(22) = 6.86, p < .001. This means that the difference between the average score before and after training is significant and not accidental. Despite the lack of use of innovative methods, the students of the control group also demonstrated positive dynamics in mastering the educational material, which may be due to the natural learning effect, consolidation of knowledge and repetition. However, the effectiveness of such an improvement should be evaluated in comparison with the results of the experimental group.

Table 3.3.2 *Results of Paired T-test of Control group*



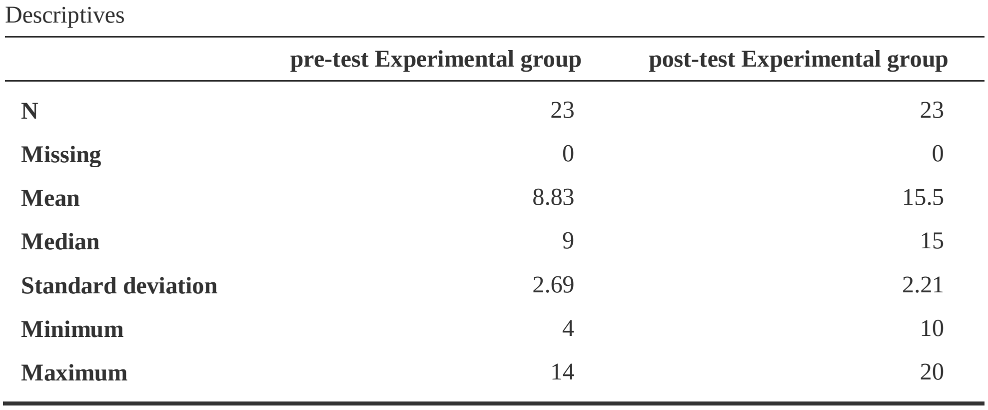
Paired Samples T-Test

			statistic	df	p
post-test Score	pre-test Score	Student's t	6.86	22.0	< .001

Note. H_a $\mu_{\text{Measure 1 - Measure 2}} \neq 0$

Speaking about the second group in our study, 23 students from the experimental group participated in the pretest, with no missing data reported. The average score was 8.83 and the median score was 9, suggesting a moderate level of baseline knowledge prior to the implementation of the STEM-based instruction. The standard deviation is 2.69, which indicates a moderate variability in the results. The minimum score is 4, the maximum is 14, which demonstrates the students' multi-level preparedness. These indicators provide a rationale for further analysis of the effectiveness of the STEM approach after the posttest.

Table 3.3.3 *Descriptive statistics of pre and post test results of Experimental group*



Descriptives

	pre-test Experimental group	post-test Experimental group
N	23	23
Missing	0	0
Mean	8.83	15.5
Median	9	15
Standard deviation	2.69	2.21
Minimum	4	10
Maximum	14	20

The results of the final testing of the students of the experimental group who were trained according to the integrative STEM unit plan confirm the high level of effectiveness of this model. The average score was 13.2 with a median of 13, which indicates a stable and uniform positive trend among the majority of students.

At the end of the STEM lesson cycle, none of the participants showed extremely low results: the minimum score was 7, and the maximum score was 19 out of a possible range. This expansion of the range towards high results indicates that some of the students have not just improved their knowledge, but have gone beyond the basic level, demonstrating a deep understanding of the material, analytical and practice-oriented skills.

Additionally, it should be noted that the standard deviation (2.64), compared with the entrance test, remains within the acceptable range, which indicates that the entire class as a whole has moved up the academic scale, and the improvements are not the result of the progress of individual students, but reflect a systemic positive trend.

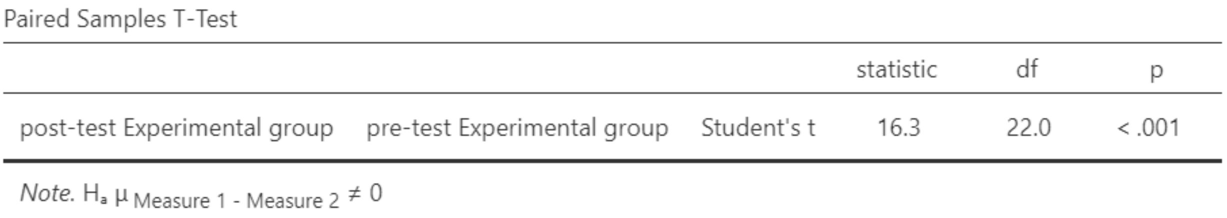
This result is a consequence of the comprehensive implementation of the STEM methodology, which includes:

- interdisciplinary integration (links with physics, mathematics and technology),
- engineering mini-projects and practical tasks,
- Active use of digital platforms and simulations,

Teamwork, engagement, and independent search for solutions.

Thus, the final scores not only confirm a significant increase in academic knowledge, but also are an indicator of the formation of modern competencies such as critical thinking, project thinking and the ability to apply theory in practice - which is the key goal of STEM education in the context of the updated school chemistry course. The results of the pre- and post-test of students who were trained in the STEM approach were compared. The analysis showed a highly significant difference between the results: t(22) = 16.3, p < .001. This means that the difference between the averages before and after training is statistically significant with a high degree of confidence. Such a high t index and an extremely low p value allow us to conclude that there is a significant increase in the level of knowledge of students, which confirms the effectiveness of the STEM methodology. The results clearly demonstrate that after completing STEM training, students scored significantly higher than before the intervention. Thus, the STEM methodology had a positive and significant impact on the academic performance of the students in the experimental group.

Table 3.3.4 *Results of Paired T-test of Experimental group*



Paired Samples T-Test

			statistic	df	p
post-test Experimental group	pre-test Experimental group	Student's t	16.3	22.0	< .001

Note. H_a $\mu_{\text{Measure 1 - Measure 2}} \neq 0$

To more accurately assess the impact of the STEM approach on student learning outcomes, an analysis of covariance (ANCOVA) was performed, in which the scores of the pre-test were used as covariates, and the group factor reflected belonging to an experimental or control group. This made it possible to exclude the influence of the initial level of knowledge and objectively compare the effectiveness of pedagogical approaches.

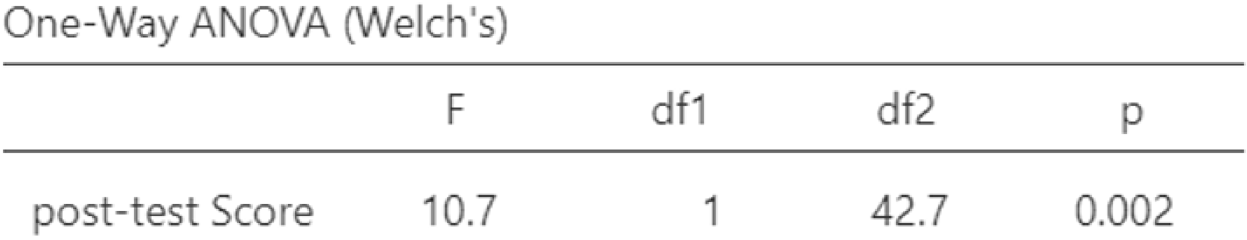
Table 3.3.5 *Results of ANCOVA based on the results of pre- and post-test of both control and experimental group*

	Sum of Squares	df	Mean Square	F	p
pre test	79.4	1	79.38	18.8	<.001
Group	78.4	1	78.44	18.6	<.001
Residuals	181.7	43	4.22		

The analysis showed that both the covariate (the results of the pre-test) and the "group" factor (STEM versus traditional learning) had a statistically significant effect on the results of the post-test. The F value for the pre-test was 18.8 ($p < .001$), which indicates the importance of the students' initial level of knowledge. However, when controlling for this factor, the difference between the groups also remained significant ($F = 18.6$; $p < .001$), which confirms the effectiveness of the STEM approach in teaching chemistry.

Thus, the STEM learning methodology has a significantly more positive impact on academic achievement compared to the traditional method, even when taking into account the preliminary level of training.

Table 3.3.6 *Results of post-test score one-way ANOVA analysis between control and experimental groups*



One-Way ANOVA (Welch's)

	F	df1	df2	p
post-test Score	10.7	1	42.7	0.002

Also, a one-way ANOVA was conducted to measure the differences in post-test scores between the control and experimental groups, without adjusting for any covariates. The analysis aimed to determine whether the implementation of STEM-based lessons had a statistically significant effect on students' academic performance. The results of the one-Way analysis of variance (One-Way ANOVA using the Welch method) showed the presence of statistically significant differences in the post-test results between the groups: $F(1, 42.7) = 10.7$, $p = 0.002$. Since the value of $p < 0.05$, the null hypothesis about the absence of differences between the average values is rejected. This means that the difference in the level of academic achievement between the control and experimental groups is significant. The data obtained confirm that the use of different methods (traditional and STEM) had different effects on student outcomes.

DISCUSSION

To achieve the goals of Master thesis, various statistical and empirical procedures aimed at verifying the hypothesis were carried out within the framework of this study. The hypothesis of this master's thesis is as follows: "An integrative STEM approach to chemistry teaching promotes a higher level of academic achievement and student engagement compared to traditional teaching methods, through interdisciplinarity, practical focus and increased motivation."

4.1 Core Elements and Design Principles of an Effective Integrative STEM Unit Plan

Based on this hypothesis, the main goal of the work was formulated - to explore and test the possibilities of using STEM methodology in the process of teaching chemistry in the 10th grade, as well as to develop an integrative unit plan aimed at deepening students' knowledge, developing critical thinking, increasing interest in the subject and developing interdisciplinary analysis skills. In the course of the study, in order to provide and answer the first question, a methodological guide for teachers was developed, lessons were taught on it, and tests were taken to compare the analysis and questions were taken into account in the difficulties of implementing and creating a plan for the STEM methodology. A number of modern studies also emphasize the importance of a well-thought-out structure and content of integrative STEM programs, which is consistent with the results of our research. For example, Lair and Maule (2023) presented an integrated chemistry and physics program based on solving real-life problems. The practical part included laboratory experiments, computational tasks, and small engineering projects that required students to apply knowledge in practice. These elements largely echo our approach to developing a STEM plan, which also focused on practical activities and interdisciplinary tasks. The use of digital simulations and formative assessment, according to the authors, helped not only to increase students' motivation, but also to deepen their understanding of the subject, which we also observed in the experimental group of our study.

Similar pedagogical principles can be traced in the two-year integrated biology and chemistry program described by S. Squire (1995). The key emphasis is placed on a constructivist approach to learning: students first studied the topic through practical activities, then comprehended the concepts and applied them in new situations. During the course, they participated in scientific projects, collective discussions, performed laboratory experiments and wrote thematic essays. This approach, of course, contributes not only to the formation of a stable understanding of complex topics, but also to the development of critical thinking skills-an effect that we sought to achieve with our STEM plan.

The work of Jumamuratov and Kaipbergenov (2023) touches on a similar topic-the authors emphasize the need to introduce project work and experiments into the school chemistry course. Although their research does not include an experimental part, the proposed recommendations confirm the expediency of interdisciplinary integration and orientation towards the practical application of knowledge-the approaches that form the basis of our curriculum.

It is also worth noting the research of Mammadov (2015), which examines the model of integrative teaching of chemistry in conjunction with other natural sciences. Despite the lack of a detailed description of the digital resources used, the author pays attention to laboratory work and modeling of chemical processes as important tools for understanding formation. In our study, this aspect was expanded and supplemented: modern platforms PhET, ChemSketch and Tinkercad were used, which allowed students to visualize molecules, create models and design their own solutions, which made the process more visual and exciting.

Thus, an analysis of the literature confirms that the elements embedded in our STEM unit plan-laboratory practice, digital tools, engineering tasks and interdisciplinary communications-are already being successfully used in foreign and domestic developments. This gives our methodology additional validity and demonstrates its relevance in the modern educational context.

4.2 Impact of the STEM Unit Plan on Students’ Conceptual Understanding and Skill Development

Continuing the topic of the discussion of scientific work, in order to provide an answer to the second question, a survey was conducted among students in order to find out their knowledge, level of knowledge and overall involvement in the methodology. Drawing on the work of other authors such as the Lair and Maule study (2023) demonstrates that the introduction of an integrated STEM program has a significant impact on the development of students' conceptual understanding and problem-solving skills. Students took part in laboratory activities, engineering activities, and calculations related to aspects of physico-chemical phenomena such as energy, momentum, and power. This type of learning allowed them to not only apply formulas, but also to meaningfully engage in data analysis. This particular mode of learning let students make connections between theory and its application in the world, which made it more meaningful in terms of solving real world problems - and this is entirely consistent with our research question.

The Rohde (2019) study demonstrates that students need to take part in the process through active assessment strategies and practice - orientated assessments. The author notes that though STEM approaches, students demonstrated they had a better mastery of scientific concepts, and demonstrated a higher cognitive activity level when engaging in solving non-standard tasks. Thus, it confirms that project and practical tasks contribute towards understanding and memorization of the material learned.

In a study that Rahmawati et al. (2019) conducted about student engagement during the design and the defence of projects that integrated chemistry and an engineered solution, the authors noted students learned how to state chemical problems, hypothesize a solution, design prototypes, and analyze the data collected. Their approach developed students both conceptual understanding and flexible thinking skills, including critical thinking skills and causal analysis.

Stohlmann, Moore, and Roehrig (2012) also emphasize that the integration of STEM components - specifically using project activities, demonstrates a positive effect on students' comprehension in science and applying the concepts learnedThe authors' opinion stresses the importance of whole assignments where Science, Technology, Engineering and Math (STEM) connect and resolve a complex issue in authentic contexts. The STEM whole study develops not only intrinsic motivation but also well-formed independent problem-solving skills with a contemporary discipline framework.

As indicated, all of the articles reviewed indicated a practice-based, interdisciplinary and active stem study approach strengthened conceptualisation and problem-solving. this style of learning correlate well with the findings from the experiment and the survey conducted at the beginning of the study to gain an understanding of the student's existing knowledge and competencies. The students in the experimental group approached mastery of chemical topics and independent thought better than the control group.

The study results tell us, along with extended observations of the experimenter's experience in the process of implementing STEM study, suggest the approach of integrated STEM education provided does verify the ideas behind transformations in integrative STEM learning and did capture the benefits not only improvements in their learning but allowed students to cultivate a brain frame of a continued effort into studying chemistry. In whatever capacity, all representations are exemplary of the endorsable value of fostering transformational learning actions for STEM learning, use that as a model for modernizing the school educational experience.

Under the conditions of the Kazakhstani educational system, we are excited to find that, transformational learning approaches are needed. Students struggle with applying theoretical knowledge to practice situations and then linking their learning to their real-life applications. The introduction of the STEM model was a comforting solution to a concern of linking educational materials to legitimate life settings, as shown by the improvements in the students' educational motivations, participation, and academic results for the students in the experimental group.

4.3 Improvements in Student Engagement and Academic Outcomes Following Implementation

Further, literature exists to show that the inclusion of an integrated STEM study model positively impacts student participation and academic performance. Rahmawati et al., (2019) pointed out that the use of a STEAM model that included interdisciplinary connections and practical learning had significant cognitive involvement, engagement and purpose for the learners of this study. Experiencing the studies maintained and strengthened students interest in chemistry and evident interest in learning, with mimicking features of real-world challenges related to design and engineering. Similarly, findings in Rohde's (2019) dissertation highlighted student engagement by reporting gains in their level of participation and performance academically upon inclusion of STEM developments into teaching and learning. A significant component of the study was the opportunity to utilize formative assessment, collaborative- group project, and independent presentations and self-reflections to importantly, form conceptual knowledge and not only practice skills, but development the opportunity, and skills for study were with intention. Lastly, Kennedy and Odell (2014) emphasized deliberately making instructional events relevant, under those conditions including a hands-on learning environment. They note research confirms STEM education as providing an opportunity to engage science learners in "active" experiences; less in terms of learning to challenges about real-life experiences and more effectively impacts significantly to know those learners who were otherwise uninterested in some of those opportunities or already skilled at the activities.

When comparing these findings to the results of the present study, there’s clear alignment. Students in the experimental group became more active during lessons, showed increased interest in chemistry, and achieved better post-test results-mirroring the patterns described in the literature. This reinforces the conclusion that STEM-based instruction doesn’t just make learning more interactive and meaningful, it also directly improves motivation and academic success in chemistry.

CONCLUSION

During the analysis of the collected data in the framework of this study, convincing answers to the formulated research questions were obtained and the main hypothesis was confirmed. The results demonstrate that the introduction of a STEM approach in chemistry teaching significantly improves the effectiveness of the educational process compared to traditional methods. The use of modern educational strategies, such as digital platforms, gamification elements, modeling, project activities, interdisciplinary assignments and teamwork, not only promotes deeper learning of the material, but also develops students' critical thinking, logical thinking, independence and creativity.

It was revealed that the students in the experimental group, where STEM components were used, demonstrated higher results in the results of surveys and diagnostic tasks compared with the control group, which was trained using the traditional method. This allows us to conclude that the integration of STEM approaches into the teaching process contributes to the better assimilation of new knowledge, as well as the formation of practice-oriented skills. The results confirm the relevance of introducing innovative pedagogical approaches into the education system of Kazakhstan, especially in the context of teaching natural sciences. It also highlights the need for continuous professional development of teachers who are able to adapt and implement modern teaching methods in a rapidly changing educational landscape.

Modern approaches applied within the framework of STEM methodology ensure the active involvement of students in the educational process. They no longer act as passive listeners, but become full-fledged participants in educational interaction. Digital tools and practical tasks allow students to establish interdisciplinary connections, apply knowledge in non-standard situations, and develop research skills. This makes the learning process more visual, motivating, and focused on real-life contexts.

The final results of the study showed that traditional teaching methods do not provide significant dynamics in student development, while the STEM approach has a positive impact on both academic achievement and motivation. This confirms that the introduction of modern methods in chemistry teaching is not just an innovation, but an urgent necessity aimed at preparing students for life and work in a rapidly changing world where skills of systems thinking, interdisciplinary approach and digital literacy are in demand.

Based on what this study has shown, there are a few clear steps that can help move chemistry education in Kazakhstan forward-especially when it comes to using

STEM in a meaningful way. First, it makes sense to start applying STEM-based lesson plans more widely in secondary schools, particularly in science subjects. These lessons should be practical, flexible, and connected to real-life situations so that students stay curious and learn to think critically. But to make that happen, teachers need real support. That means more professional development-not just theory, but hands-on workshops that help them feel confident using digital tools, trying out interdisciplinary tasks, and leading project-based lessons.

Alongside that, the curriculum itself needs some updating. Teachers should have the freedom to try new methods without feeling like they're falling behind on required content. More investment is also needed in things like lab equipment, simulations, and educational platforms that make STEM learning more interactive and engaging. Schools should also create opportunities for teachers from different subjects-like chemistry, math, and ICT-to work together. When students see how these subjects connect, it makes their learning more relevant and useful.

Finally, it would be valuable to test this approach in more schools, including different types of institutions and regions, to see how it works in other settings. The more we learn, the more we can improve. Taking all of these steps will help make chemistry not just a subject to study, but a tool to understand and shape the world-exactly what 21st-century education should be about.

CHALLENGES AND LIMITATIONS

Due to the fact that each topic of the STEM methodology has 4 parts, it took a lot of time to teach the methodology, as it was not possible to fully implement it into the learning process.

Due to limited physical resources (for example, fully equipped laboratories), some practical components had to be adapted or digitally modeled, which may not fully correspond to the experience of real laboratory work.

The lack of textbooks on teaching methods, therefore, it was decided to create methodological guidelines for teaching STEM methods.

Therefore, this study requires further refinement and adjustments to obtain more accurate statistical results and to confirm the hypothesis with a higher degree of confidence.

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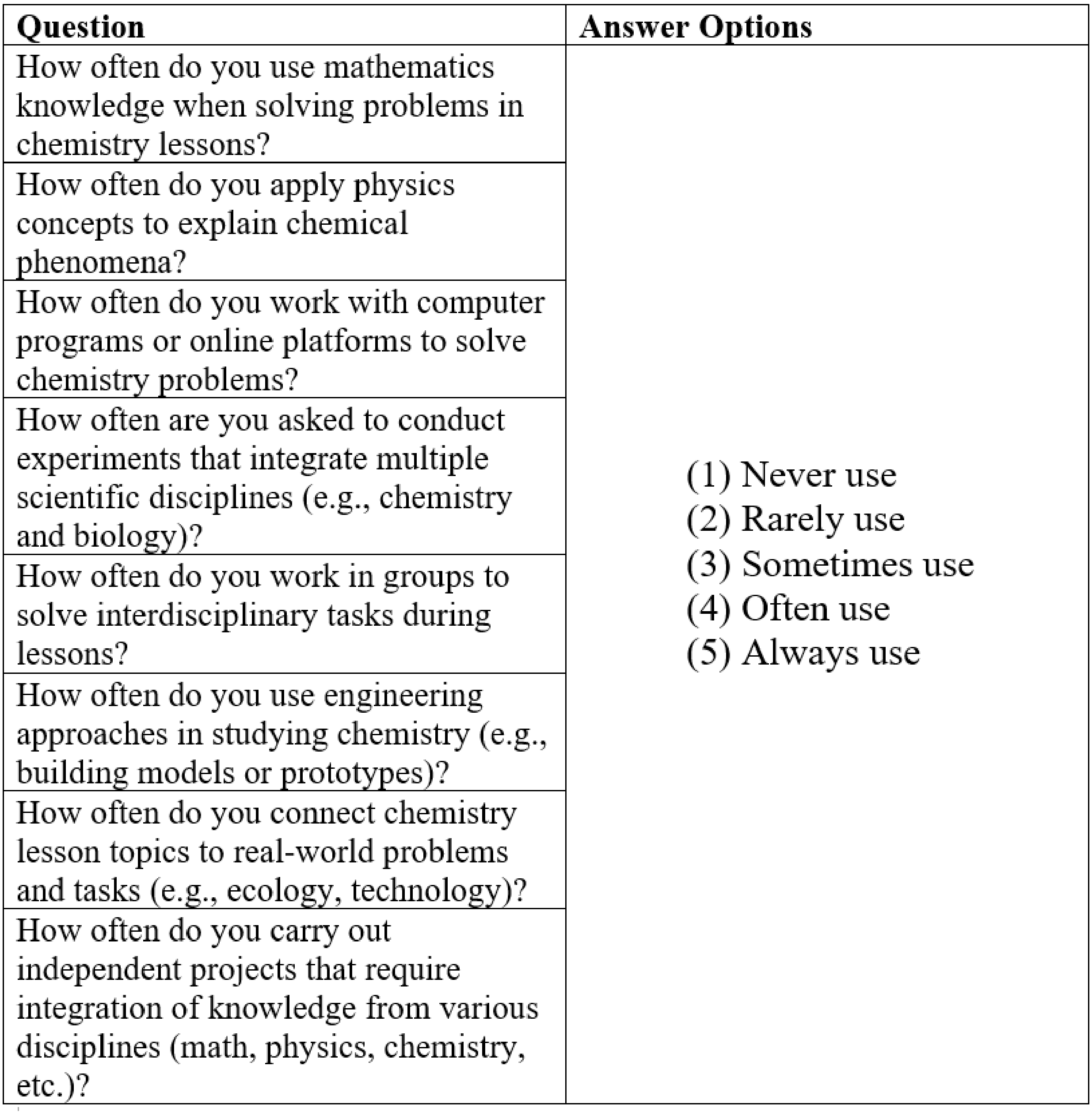
APPENDICES

Appendix 1. *Questions of survey*



Question	Answer Options
How often do you use mathematics knowledge when solving problems in chemistry lessons?	(1) Never use (2) Rarely use (3) Sometimes use (4) Often use (5) Always use
How often do you apply physics concepts to explain chemical phenomena?	
How often do you work with computer programs or online platforms to solve chemistry problems?	
How often are you asked to conduct experiments that integrate multiple scientific disciplines (e.g., chemistry and biology)?	
How often do you work in groups to solve interdisciplinary tasks during lessons?	
How often do you use engineering approaches in studying chemistry (e.g., building models or prototypes)?	
How often do you connect chemistry lesson topics to real-world problems and tasks (e.g., ecology, technology)?	
How often do you carry out independent projects that require integration of knowledge from various disciplines (math, physics, chemistry, etc.)?	

Appendix 2. *pre- and post-test questions*

Lesson 1: Atoms and Chemical Structures

1. Which statement correctly describes the structure of an atom?

A. Electrons have more mass than neutrons
B. Electrons revolve around the nucleus in fixed orbits
C. Protons are located in the electron cloud
D. Neutrons carry a positive charge
Correct answer: B

2. Which element has the electron configuration $1s^2 2s^2 2p^6 3s^1$?

A. Neon
B. Magnesium
C. Sodium
D. Fluorine
Correct answer: C

3. What is the charge of an electron?

A. -1
B. 0
C. +1
D. -2
Correct answer: A

4. What is the total number of electrons in a neutral calcium atom?

A. 40
B. 22
C. 20
D. 18
Correct answer: C

5. What is the mass number of an atom with 11 protons and 12 neutrons?

A. 12
B. 22
C. 23
D. 11
Correct answer: C

Lesson 2: Rate of Reaction

1. What factor increases the rate of a chemical reaction by lowering the activation energy?

A. Reactant concentration
B. Catalyst
C. Temperature
D. Pressure
Correct answer: B

2. Which graph best shows the relationship between concentration and rate of reaction?

A. A direct proportional line

B. A sinusoidal curve
C. A decreasing curve
D. A horizontal line
Correct answer: A

3. Which method increases the surface area of a solid reactant?

A. Dissolving in water
B. Cooling the system
C. Using powdered form
D. Using larger chunks
Correct answer: C

4. How does increasing temperature affect the rate of reaction?

A. Increases the rate
B. Stops the reaction
C. No effect
D. Decreases the rate
Correct answer: A

5. Which of the following best defines the rate of a chemical reaction?

A. Energy absorbed during reaction
B. Volume of gas released
C. Change in concentration per time
D. Mass of products formed
Correct answer: C

Lesson 3: Redox Reactions

1. Which species is oxidized in the reaction: $2Mg + O_2 \rightarrow 2MgO$?

A. O_2
B. MgO
C. Mg
D. O^{2-}
Correct answer: C

2. What is the oxidation number of chlorine in $KClO_3$?

A. +5
B. +1
C. +3
D. -1
Correct answer: A

3. Which process represents reduction?

A. Addition of oxygen
B. Loss of electrons
C. Formation of acid
D. Gain of electrons
Correct answer: D

4. What is the oxidizing agent in a redox reaction?

A. Substance that loses electrons
B. Substance that forms gas
C. Substance that gains electrons
D. Substance that is neutral
Correct answer: C

5. Which reaction is an example of a redox reaction?

A. $HCl + NaOH \rightarrow NaCl + H_2O$
B. $CH_3COOH + NaHCO_3 \rightarrow CO_2 + H_2O + CH_3COONa$
C. $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$
D. $BaCl_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaCl$
Correct answer: C

Lesson 4: Introduction to Organic Chemistry

1. What is the homologous series of alkanes?

A. C_nH_{2n-2}
B. C_nH_{2n}
C. C_nH_{2n+2}
D. $C_nH_{2n}O_2$
Correct answer: C

2. Which compound contains a carboxyl group?

A. CH_3COOH
B. C_2H_5OH
C. C_2H_6
D. CH_4
Correct answer: A

3. Which compound is a hydrocarbon?

A. C_2H_6
B. CH_3Cl
C. CH_3COOH

D. CH_3OH
Correct answer: A

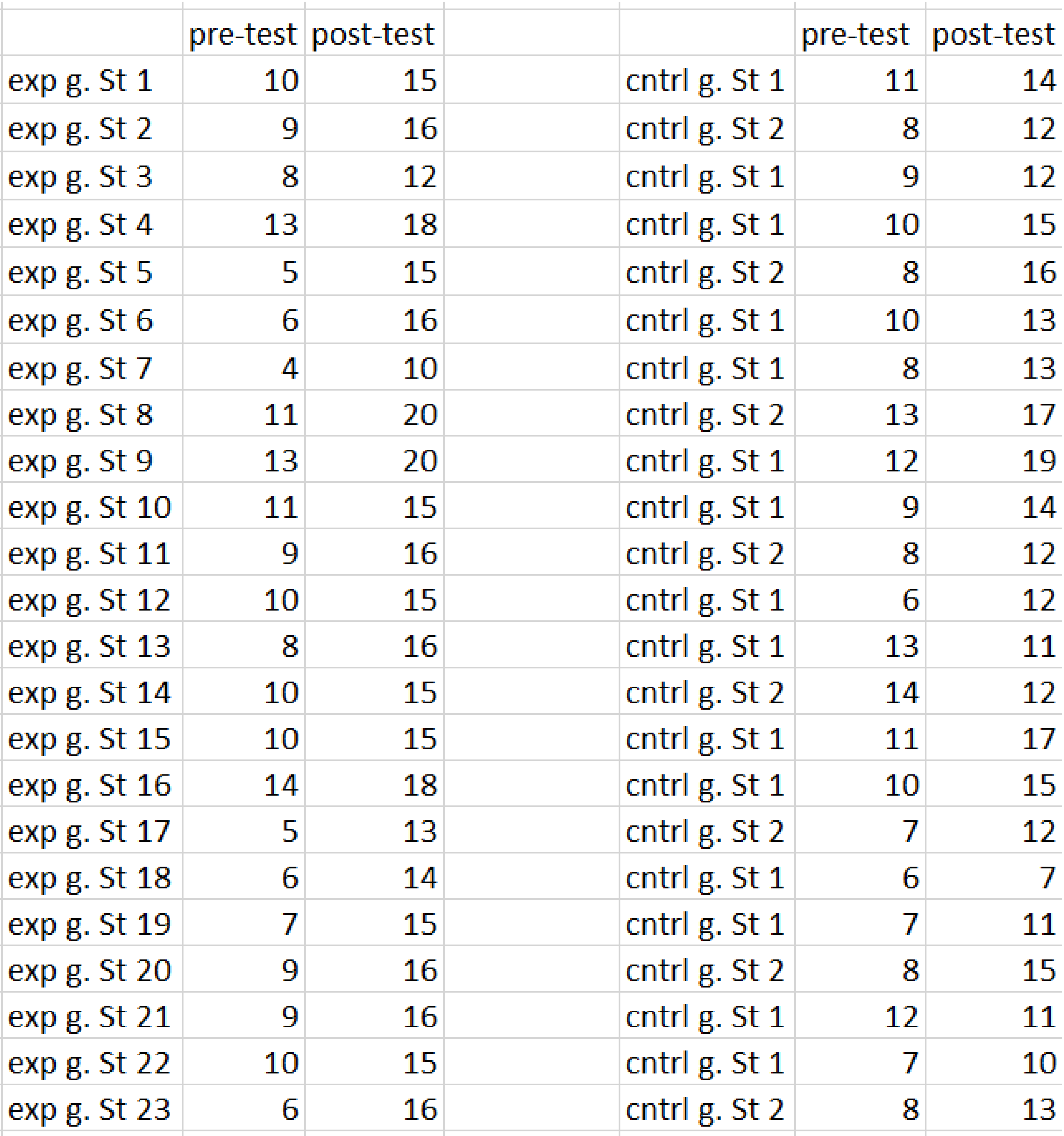
4. Which functional group is found in alcohols?

A. –OH
B. –COOH
C. $–NH_2$
D. –CHO
Correct answer: A

5. What type of bond is found in alkenes?

A. Single
B. Triple
C. Ionic
D. Double
Correct answer: D

Appendix 3. *pre- and post-test result*



	pre-test	post-test			pre-test	post-test
exp g. St 1	10	15		cntrl g. St 1	11	14
exp g. St 2	9	16		cntrl g. St 2	8	12
exp g. St 3	8	12		cntrl g. St 1	9	12
exp g. St 4	13	18		cntrl g. St 1	10	15
exp g. St 5	5	15		cntrl g. St 2	8	16
exp g. St 6	6	16		cntrl g. St 1	10	13
exp g. St 7	4	10		cntrl g. St 1	8	13
exp g. St 8	11	20		cntrl g. St 2	13	17
exp g. St 9	13	20		cntrl g. St 1	12	19
exp g. St 10	11	15		cntrl g. St 1	9	14
exp g. St 11	9	16		cntrl g. St 2	8	12
exp g. St 12	10	15		cntrl g. St 1	6	12
exp g. St 13	8	16		cntrl g. St 1	13	11
exp g. St 14	10	15		cntrl g. St 2	14	12
exp g. St 15	10	15		cntrl g. St 1	11	17
exp g. St 16	14	18		cntrl g. St 1	10	15
exp g. St 17	5	13		cntrl g. St 2	7	12
exp g. St 18	6	14		cntrl g. St 1	6	7
exp g. St 19	7	15		cntrl g. St 1	7	11
exp g. St 20	9	16		cntrl g. St 2	8	15
exp g. St 21	9	16		cntrl g. St 1	12	11
exp g. St 22	10	15		cntrl g. St 1	7	10
exp g. St 23	6	16		cntrl g. St 2	8	13