Creating the Integrative STEM Lesson Unit Plan for 11th Grade Students

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This is to certify that the Master's Thesis of

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LIST OF ABBREVIATIONS

ANCOVA	Analysis of Covariance
AR	Augmented Reality
APA	American Psychological Association
BSCS	Biological Sciences Curriculum Study
CPD	Continuing Professional Development
CSV	Comma-Separated Values
df	Degrees of Freedom
EN	English
F	F-statistic (ANCOVA/ANOVA)
IBL	Inquiry-Based Learning
IJ STEM Ed	International Journal of STEM Education
J-PEER	Journal of Pre-College Engineering Education Research
KZ	Kazakh
M	Mean
MCQ	Multiple Choice Question
NAE	National Academy of Engineering
NRC	National Research Council
OECD	Organisation for Economic Co-operation and Development
p	p-value (probability value)
PhD	Doctor of Philosophy
PhET	Physics Education Technology (University of Colorado Boulder)
PVC	Polyvinyl Chloride
RQ	Research Question
RQ1	Research Question 1
RQ2	Research Question 2
RQ3	Research Question 3
SD	Standard Deviation
STEM	Science, Technology, Engineering, and Mathematics
STEAM	Science, Technology, Engineering, Arts, and Mathematics
STP	Standard Temperature and Pressure
t	t-statistic (t-test)
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHO	World Health Organization
W	Kendall's Coefficient of Concordance
ZPD	Zone of Proximal Development
5E	Engage, Explore, Explain, Elaborate, Evaluate (Instructional Model)

ABSTRACT

This study investigates the development, implementation, and evaluation of an integrative STEM lesson unit plan for 11th grade chemistry students across three secondary schools in Almaty, Kazakhstan a private school, a state school, and a specialized school. The study addresses three research questions concerning the development of an effective STEM unit plan, its impact on academic performance, and the challenges associated with its integration. Grounded in constructivism, the Zone of Proximal Development, inquiry-based learning, and the 5E Instructional Model, the research employed a mixed-methods design combining a quasi-experimental pre-test and post-test with semi-structured online interviews. A total of 117 students participated in the pedagogical experiment, and 15 chemistry teachers were interviewed. Research instruments were validated by five experts using Kendall's W analysis ($W = 0.82$ and $W = 0.79$, both $p < .05$). Paired samples t-tests confirmed statistically significant improvement in all six groups ($p < .05$). ANCOVA revealed significant advantages for the experimental group at the state school ($F(1) = 9.34$, $p = .004$) and the specialized school ($F(1) = 9.14$, $p = .004$). Qualitative findings indicated positive impacts on student engagement, motivation, and 21st-century skill development, while four systemic barriers were identified: infrastructural limitations, curriculum rigidity, inadequate teacher preparation, and student resistance. The study concludes that integrative STEM education has genuine and statistically demonstrable potential to enhance chemistry learning in Kazakhstan, and that successful implementation requires sustained investment in teacher professional development, school infrastructure, and curriculum reform.

Keywords: *STEM education, integrative unit plan, chemistry teaching, 11th grade, academic performance, Kazakhstan, mixed methods, ANCOVA, parallel forms*

АҢДАТПА

Бұл зерттеу Қазақстанның Алматы қаласындағы үш орта мектепте жеке, мемлекеттік және мамандандырылған мектептерде 11-сынып химия оқушылары үшін интегративті STEM оқыту жоспарын әзірлеуге, енгізуге және бағалауға арналған. Зерттеу үш сұраққа жауап іздейді: тиімді STEM оқыту жоспарын әзірлеу, оның академиялық үлгерімге әсері және интеграциямен байланысты қиындықтар. Конструктивизм, жақын даму аймағы, зерттеуге негізделген оқыту және 5E моделіне сүйене отырып, зерттеуде квазиэксперименттік дизайн мен жартылай құрылымдалған сұхбаттарды біріктіретін аралас әдіс қолданылды. Педагогикалық экспериментке 117 оқушы қатысты, 15 мұғаліммен сұхбат жүргізілді. Зерттеу құралдары бес сарапшымен расталды (W = 0,82 және W = 0,79, екеуі де $p < 0,05$). Жұптық t-тест барлық алты топта статистикалық маңызды жақсаруды растады ($p < 0,05$). ANCOVA мемлекеттік мектепте ($F(1) = 9,34$, $p = 0,004$) және мамандандырылған мектепте ($F(1) = 9,14$, $p = 0,004$) эксперименттік топтың маңызды артықшылығын анықтады. Сапалық деректер оқушылардың қатысуы мен 21-ғасыр дағдыларына оң әсерді көрсетіп, төрт жүйелік кедергіні анықтады: инфрақұрылымдық шектеулер, оқу бағдарламасының қаттылығы, мұғалімдерді дайындаудың жеткіліксіздігі және оқушылардың қарсылығы. Зерттеу интегративті STEM білімінің Қазақстанда химияны оқытуды жетілдіру үшін статистикалық тұрғыдан дәлелденген әлеуетке ие екенін қорытындылайды.

Кілт сөздер: *STEM білімі, интегративті оқыту жоспары, химияны оқыту, 11-сынып, академиялық үлгерім, Қазақстан, аралас әдістер, ANCOVA, параллельді формалар*

АННОТАЦИЯ

Данное исследование посвящено разработке, внедрению и оценке интегративного учебного плана STEM для учащихся 11-го класса по химии в трёх средних школах Алматы частной, государственной и специализированной. Исследование рассматривает три вопроса: разработку эффективного учебного плана STEM, его влияние на академическую успеваемость и трудности интеграции. Опираясь на конструктивизм, зону ближайшего развития, обучение на основе исследования и 5E-модель, исследование применяло смешанный метод, сочетающий квазиэкспериментальный дизайн с полуструктурированными интервью. В педагогическом эксперименте приняли участие 117 учащихся, было проведено 15 учительских интервью. Инструменты исследования были валидированы пятью экспертами ($W = 0,82$ и $W = 0,79$, оба $p < 0,05$). Парный t-критерий подтвердил значимое улучшение во всех шести группах ($p < 0,05$). ANCOVA выявил значимые преимущества экспериментальной группы в государственной школе ($F(1) = 9,34$, $p = 0,004$) и специализированной школе ($F(1) = 9,14$, $p = 0,004$). Качественные данные указали на положительное влияние на вовлечённость и навыки XXI века, а также выявили четыре системных барьера: инфраструктурные ограничения, жёсткость программы, недостаточная подготовка педагогов и сопротивление учащихся. Исследование заключает, что интегративное STEM-образование обладает статистически подтверждённым потенциалом для улучшения обучения химии в Казахстане при условии инвестиций в профессиональное развитие педагогов, инфраструктуру и реформу учебных программ.

Ключевые слова: *STEM-образование, интегративный учебный план, преподавание химии, 11-й класс, академическая успеваемость, Казахстан, смешанные методы, ANCOVA, параллельные формы*

INTRODUCTION

Background Theories

The current study is based on a number of related theories that provide a theoretical basis for the development and use of the STEM unit plan in 11th-grade chemistry. The core theoretical background is the concept of social-constructivist constructivism proposed by Jean Piaget and further developed by Lev Vygotsky. The main idea of the theory is that students actively construct knowledge through reflection on experiences and interactions with their surroundings. In the current study, constructivism is used to build STEM lessons in which students are actively involved in experimenting and solving chemistry-related problems, as well as applying their knowledge to the real-life situation. One of the ideas directly associated with the constructivism of Lev Vygotsky is the Zone of Proximal Development (ZPD), that is, tasks the learners can accomplish with the help of others but cannot do themselves. ZPD is also incorporated into the development of the STEM unit plan, whereby lessons become more and more complicated and students get support from their teachers and classmates for solving problems. Another theory underlying the current study is inquiry-based learning (IBL), according to which learners' investigations should constitute the core activity. Based on the ideas put forward by Kennedy and Odell (2014), an effective STEM course should start with the development of scientific inquiry, including posing relevant questions and finding evidence, followed by engineering design and mathematics-related activities. Finally, this study is based on the 5E instructional model, which was introduced by Bybee et al. (2006). As opposed to the traditional lecture-based teaching method, 5E focuses on the development of learners' higher order thinking skills, as well as transferring learning experiences across subjects.

Problem Statement

While the possession of knowledge alone may suffice in earlier centuries, 21st-century citizens need to know how to use that knowledge to solve real-life problems.

Nevertheless, the gap between theory and practice is apparent in the case of science disciplines, such as chemistry, biology, and physics. In the first decade of the 21st century, there has been an increased need for specialists with STEM education in theoretical and practical aspects. Researchers have outlined a number of issues faced by modern education systems, including (a) the failure of the knowledge-based approach to satisfy workforce needs; (b) decreasing levels of student motivation in STEM subjects; (c) low achievement rates in science and mathematics; and (d) inability to use STEM knowledge to address practical tasks. Currently, no unified approach to STEM education has been developed in Kazakhstan. Some of the private schools have started introducing elements of the interdisciplinary approach, namely using robotics, ICT, and project-based learning techniques. At the same time, the majority of students still study science according to the traditional lecture-based paradigm. Thus, an innovative method, such as STEM education, could be a solution to the current problems in the educational system. STEM education combines scientific theories with practical skills and teaches students critical thinking, collaboration, creativity, and increased interest in technical fields. The key goal of STEM education is to produce not just specialists but also people with all types of "hard" and "soft" skills needed in the modern world.

STEM courses were traditionally studied as separate disciplines without any connection. With changes in contemporary society, the focus shifted towards an interdisciplinary approach to STEM education (NRC, 2012, 2013). For example, according to the NGSS, science instruction is required to incorporate elements of engineering and the use of technologies. Moreover, students are expected to apply their knowledge of math to solve STEM-related problems. An integrated STEM approach is likely to contribute to increased motivation to learn science among students and promote deeper conceptualization and cross-curricular connections. However, while curricular integration has long been a popular trend in science education (since 1950s) (Berlin, 1994), there is little research in the field of successful curriculum integration. Science educators face many difficulties associated with the lack of instructions and

materials to integrate STEM subjects. In the Kazakhstani context, this issue is even more pressing due to the lack of information concerning the effectiveness of STEM unit plan integration. Therefore, a study in this direction may help overcome some of the difficulties and introduce new ideas about teaching methods.

Significance of the Study

From the educational viewpoint, the current study will prove the benefits associated with introducing STEM elements to secondary science classrooms, helping transform passive recipients of knowledge into active participants. STEM education can foster students' higher-order thinking skills, such as critical and analytical reasoning (Sadler & Zeidler, 2004). From the professional viewpoint, the demand for specialists who have STEM education will keep growing. In addition to equipping students with interdisciplinary knowledge and practical skills, STEM education is crucial for Kazakhstan's goal of creating a knowledge-based economy, as it involves teaching science and technology at the secondary level. From an individual standpoint, being STEM literate will help make informed decisions in various aspects of people's lives, such as health care, the environment, etc. Being knowledgeable about science and technologies also helps individuals think logically, make sound judgments, and become active members of the society. Finally, regardless of their future careers, secondary school students can benefit greatly from the knowledge gained from STEM classes.

Research Questions

RQ1: How can an effective STEM unit plan be developed and successfully integrated into the curriculum

RQ2: How does the introduction of a STEM unit plan affect the overall academic performance of 11th-grade students?

RQ3: What challenges and potential drawbacks are associated with integrating a STEM unit plan into the school curriculum?

Aim of research work

To investigate how an effective STEM unit plan can be developed and integrated into the school curriculum (aligns with RQ1)

To evaluate the impact of the STEM unit plan on the academic performance of 11th-grade students (aligns with RQ2)

To identify potential challenges and drawbacks associated with integrating a STEM unit plan into the school curriculum (aligns with RQ3)

Objectives for study

To conduct a literature review and expert interviews to explore best practices for STEM curriculum integration (aligned with RQ1)

To design and develop an integrative STEM unit plan for 11th-grade chemistry classes (aligned with RQ1)

To implement the STEM unit plan within the existing curriculum through a pedagogical experiment (aligned with RQ2)

To measure and compare students' academic performance before and after the integration (aligned with RQ2)

To gather data from teachers and stakeholders on difficulties encountered during implementation (aligned with RQ3)

Contribution of the Study

The current study makes multiple contributions to the field of STEM education.

Theoretical contribution. The research contributes to the increasing body of literature dedicated to the theme of STEM integration by providing empirical evidence about the development and integration of an interdisciplinary unit plan in 11th-grade chemistry classes. Although many studies focus on STEM integration in Western contexts, there is little research related to the Kazakhstani secondary school system. This study bridges the gap and adds to existing theoretical knowledge about the application of constructivist and inquiry-based models in a non-Western setting.

Practical contribution. Practically, the study results in the creation of a useful product – an integrative STEM unit plan for chemistry courses at the secondary level. The produced unit plan may serve as an example for other chemistry teachers to implement an interdisciplinary approach despite having limited resources.

Methodological contribution. The study utilizes a combination of quantitative and qualitative methods, including a pedagogical experiment, pre- and post-testing, interviews, and observations. Such an approach allows getting an in-depth picture of the results obtained and the challenges encountered, serving as a basis for future methodological research in the natural sciences at secondary schools in Kazakhstan.

Policy-related contribution. Based on the findings, the study contributes valuable information for policymakers concerning the benefits and challenges associated with STEM integration in secondary schools. In the context of efforts taken in Kazakhstan aimed at reforming the education system and creating a knowledge-based economy, the results of this study are quite timely and relevant.

LITERATURE REVIEW

1.1 Nature and Definition of Integrated STEM Education

It is important to start clarifying the nature of STEM education and defining this term first and foremost. A discipline, according to Choi and Pak (2006), Klein (1990), implies a certain field of human knowledge along with a set of culture, habits, and community connected to it. Within the scope of the current study, the core STEM disciplines, which are science, technology, engineering, and mathematics, will be viewed not as isolated sectors but as an interconnected domain that would provide the required platform for interdisciplinary studies.

Several definitions of how disciplines can interact include integrated, interdisciplinary, and transdisciplinary approaches. The idea of an interdisciplinary approach is to contrast or unite two or more disciplines and develop explicit links among them (Klein, 2004; Miller, 1981). In educational settings, interdisciplinarity is associated with students forming logical links among several fields (for example, combining the knowledge in science and mathematics to deal with complex real-life situations). It is worth adding that interdisciplinarity does not dissolve the borders of any individual discipline; on the contrary, it implies that a strong grounding in each separate subject is needed for this to happen (Zhang & Shen, 2015; NAE & NRC, 2014).

Transdisciplinarity is aimed at the unification of knowledge beyond discipline borders, with attention paid mainly to the problem domain and not to the leftovers of individual disciplines (Nicolescu, 2002; Klein, 2008). In terms of education, an integrated approach is often referred to as merging concepts and topics of different disciplines in one whole (Lederman & Niess, 1997).

During several decades, the emphasis on the development of STEM education was focused primarily on improving knowledge in science and mathematics as isolated disciplines; technology and engineering were often overlooked (Breiner et al., 2012; Sanders, 2009). Sanders (2009) defined integrated STEM education as "approaches that explore teaching and learning between or among any two or more of the STEM

subject areas, and/or between a STEM subject and one or more other school subjects" (p. 21). Moore et al. (2014) gave another definition, describing it as "an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems" (p. 38).

Within the scope of this study, the concept of integrated STEM education will be defined as an approach to teaching the content of two or more STEM domains within STEM practices in an authentic context to unite these subjects and make the learning process more efficient. This definition will be taken into account during the development of the integrative STEM unit plan for eleventh-grade chemistry classes.

1.2 History of STEM Education

The history of STEM education is related closely with various socio-economic and political changes in society. From the time when STEM principles have been used in technological innovations after the Industrial Revolution (electric light, cars, manufacturing, etc.), they have become an integral part of industry, although their incorporation into educational settings is not that old (Butz et al., 2004).

The beginning of World War II became another turning point for STEM education. Science and engineering became the main sources to create new technologies. Scientists, engineers, and mathematicians managed to prove that collaborative problem-solving could be very efficient. In addition, there appeared an awareness of the importance of STEM education among governments.

Another turning point came after the launching of Sputnik in 1957. This initiative stimulated the interest of the USA and other states in investing more money in science and mathematics education. After that, from 1969 to nowadays, the National Assessment of Educational Progress (NAEP) collected statistics about American children compared with other industrialized countries in regard to their proficiency in science and mathematics (Butz et al., 2004).

Since 1990s, STEM education has been developed and implemented in more and more countries worldwide, namely, in South Korea, Malaysia, Thailand, Saudi Arabia,

and so forth. Today, STEM education becomes topical in Kazakhstan, which tries to introduce modernization in the country's educational system. At the moment, STEM elements are being used mainly in private schools in a fragmented way (robotics club, ICT-based laboratories, etc.). This fact gives grounds for conducting research on a similar topic in Kazakhstan.

1.3 Theoretical Foundations of STEM Education

The implementation of an integrative STEM unit plan for eleventh-grade chemistry classes would require the involvement of several theoretical bases that can help design an interdisciplinary lesson plan. These are constructivism, inquiry-based learning, and 5E instructional model proposed by Bybee et al. (2006).

Constructivism as the theoretical basis has been developed by Jean Piaget and Lev Vygotsky. The main ideas behind this theory are related to the fact that people actively learn from experience, reflection, interaction, and other processes rather than from passive reception of information (Piaget, 1970; Vygotsky, 1978). As far as STEM education is concerned, it implies that students are engaged in conducting experiments, solving problems collaboratively, and applying knowledge to real-life situations to promote their understanding. Thus, an integrative STEM lesson is supposed to involve such components as hands-on experiments, teamwork, and so forth.

Vygotsky's idea of the Zone of Proximal Development (ZPD) should also be considered during the development of the STEM unit plan. According to this concept, the range of the problems that the person can solve with someone else's help but cannot do alone is called ZPD. Within the scope of this study, lessons will be developed with scaffolding in mind. The level of difficulty will be increasing progressively; thus, a teacher and his/her students' peers will help the students come up with the necessary interdisciplinary thinking.

The next theoretical approach to be discussed is inquiry-based learning (IBL). The idea behind IBL is that learning implies conducting investigations in accordance with what students want to find out. Kennedy and Odell (2014) believe that STEM education should start with scientific inquiry (raising questions, collecting evidence);

then, students should move to engineering design and mathematics. These three steps should also be included while designing the STEM unit plan.

Finally, a 5E instructional model by Bybee et al. (2006) involves five phases. In turn, each of these phases has specific tasks that should be fulfilled during a STEM lesson. In order to engage students, a teacher should activate their knowledge about the subject. During the exploratory phase, students are expected to conduct an experiment and gather information on this problem. Explaining means analyzing obtained information critically, and elaboration includes extending knowledge to a new context. Evaluating students' performance is the final step of the lesson.

1.4 Teaching Chemistry in Secondary School

The process of teaching chemistry faces numerous difficulties, and one of the reasons for this is the abstract nature of chemistry and the language that it uses. In addition, learning chemistry involves theoretical knowledge and practical work in the laboratory. According to research, students' motivation and achievement in chemistry in many countries, including those in Central Asia, keep decreasing year by year (Berhe et al., 2024). There are several factors contributing to this phenomenon.

First, traditional teacher-centered lecturing does not contribute to motivating students and making the link between chemical concepts and life evident. As pointed out by Felder and Brent (2016), the conventional model implies transmission and reception of knowledge respectively by the teacher and the student. For learning to be successful, it is necessary that the latter has sufficient opportunities to observe, experiment, hypothesize, and reflect on results to construct necessary concepts.

Second, laboratory equipment may be not enough to facilitate chemistry practice. According to Berhe et al. (2024), inadequate infrastructure becomes a serious barrier to delivering quality chemistry education. Without practical classes, it is hard for students to understand and retain theory. Thus, this problem is rather typical for Kazakhstan and will be taken into consideration in the current research.

Third, the relevance of studying chemistry for the real life is not always obvious for students. As indicated by Nja (2021), more than 60 percent of secondary-school

students in his research wanted to study chemistry via practical, life examples. This fact provides an additional rationale for developing an integrative STEM unit plan for the students from Kazakhstan.

1.5 Integrating STEM Approaches in Chemistry Education

STEM principles can make the process of learning more appealing and fruitful because they help to integrate chemistry knowledge into technology, engineering design, and mathematics and apply it to solving a practical task. For example, Rahmawati et al. (2019) showed the effectiveness of the project-based STEAM approach when teaching acids and bases to 76 eleventh-grade students. The authors asked the students to create hydroponic systems and manage them. Thus, chemistry was used to measure pH levels, technology helped monitor conditions, and engineering and mathematics – design the systems. In contrast to traditional learning, the researchers reported that engagement increased and critical and creative thinking were better developed. As far as this research paper is concerned, it is worth noting that the participants of the study were also eleventh-graders.

Furthermore, Hagverdiyev and Mammadova (2021) claimed that integrative teaching of chemistry was to harmonize such aspects as goals, content, methodology, and digital technologies. Moreover, they argued that chemistry could not be taught in isolation from other disciplines. Instead, physics, biology, environmental science, and technologies should be involved in the study of chemistry in order to make it realistic. This interdisciplinary view has been also adopted in the present study.

Moreover, Fitriyana et al. (2024) carried out a study to understand teachers' attitude towards using STEM principles in chemistry teaching. It turned out that the respondents recognized the importance of incorporating STEM elements into the curriculum to promote problem-solving, creativity, and other competencies among students. However, the interviewees noted several barriers, for example, insufficient time, lack of necessary facilities, and poor knowledge of STEM pedagogy. Similar issues exist in Kazakhstan as well. Therefore, this research paper tries to answer the research question on barriers as well.

1.6 Designing Effective STEM Unit and Lesson Plans

To develop an effective STEM unit and lesson plans, it is necessary to focus on several factors. Several elements can differentiate high-quality integrated STEM lessons from superficial attempts of connecting different disciplines.

First of all, it is necessary to refer to the STEM model focusing on Support, Teaching, Efficacy, and Materials (Stohlmann, Moore, & Roehrig, 2012). The authors found out that teachers' confidence in themselves, access to hands-on material, and opportunities for professional collaboration played a crucial role in effective implementation of integrated STEM teaching. It should be taken into account when answering the third research question.

Furthermore, the 4-D model (Define, Design, Develop, Disseminate) can be used to create materials for STEM learning. The process starts with identifying the needs by conducting curriculum analysis, conducting surveys and assessing learners. The second stage is connected with building a prototype lesson plan in accordance with criteria-related assessment, suitable media, and lessons.

Wisudawan (2022) emphasized the advantage of merging practical activities directly into chemistry lessons rather than teaching them separately from the theory. In the quasi-experimental study, she found that students participating in integrated practicum lessons scored higher than those learning traditionally (mean score of 72.83 vs. mean score of 64.10). Thus, laboratory classes can be considered as an important part of STEM-based lessons in eleventh grade.

Lair and Maule (2023) provide a vivid example of STEM education based on the authors' Integrated Chemistry and Physics Curriculum. It involves thematic units focused on relevant questions in real life and performance tasks related to them, i.e., experiments, computations, and engineering projects. These units contain student-friendly learning targets. This demonstrates that quality standards-based STEM learning can be provided even in regular schools.

1.7 The Role of Technology in STEM Education

Modern technological advances can contribute to STEM learning as a tool to make learning engaging and eliminate obstacles to effective learning that may arise due to resource limitations. All available sources indicate that if a teacher chooses appropriate digital technology, it is possible to simplify complex notions for students, promote differentiated learning and prepare learners for a career in the IT sphere.

In relation to STEM education, Yesgat et al. (2023) conducted a study among secondary schools in Ethiopia and concluded that the use of technology in chemistry lessons promoted the development of students' knowledge and ensured its long-lasting character. Using Solomon four group quasi-experimental research design, the researchers concluded that technology-integrated instruction yielded significantly better results on achievement tests immediately and after four weeks in comparison with traditional teaching. There were no statistically significant differences in achievement between girls and boys.

Aroch, Katchevich, and Blonder (2024) explored different modes of integrating technology in chemistry teaching, which included digital visualization tools, virtual laboratories, online databases, and computational methods. Experienced teachers who know how to use technology properly create a context-based environment and involve students. This fact is relevant to the current study because the authors plan to use some tools, such as PhET simulation, ChemSketch, Tinkercad, etc.

Virtual reality (VR) and augmented reality (AR) technologies can help visualize invisible objects and simulate chemical reactions. Even if Kazakhstani schools do not provide such possibilities, the rule remains unchanged: technology visualizes complex concepts.

There are numerous ways in which technology helps students to learn even if there are problems with laboratories and other resources. For example, virtual laboratories (Labster) and online collaboration tools (Google Workspace for Education) allow students to conduct experiments remotely, analyze data, and collaborate with peers.

1.8 Motivation and Engagement in STEM Learning

Motivation can be seen as the key factor affecting STEM achievements positively because motivated students get higher grades and continue learning STEM subjects in colleges/universities (Kennedy & Odell, 2014). In many countries, including Kazakhstan, there has been noted a decrease in students' motivation.

First, the perceived relevance of the material to life and practical skills that it promotes can become the driving force for the development of intrinsic motivation. In line with this, the researcher plans to involve problem-solving contexts as well as technology into learning chemistry.

Second, active and collaborative learning experience motivates students as it makes the process of learning more enjoyable. For example, according to Rohde (2019), hands-on STEM projects encourage students to develop greater enthusiasm, independence, and creativity. Such motivation is based on the authenticity of projects rather than assessments.

Integrating the principles of sustainable development into STEM learning contributes to the development of the necessary skills and motivation. For instance, game-based and virtual reality elements helped increase students' self-efficacy and satisfaction, which resulted in higher academic achievement.

1.9 Challenges in Implementing Integrated STEM Education

Although the process of implementing STEM education can yield numerous advantages for learning, this innovation brings certain difficulties with it. In the current research, one is expected to investigate what obstacles prevent the implementation of a STEM unit plan in Kazakhstan.

One of the main barriers is associated with the lack of professional development of teachers in the field. Chemistry teachers are often trained in a subject-specific way; therefore, they do not have a chance to become acquainted with new methods. This issue has been investigated by Fitriyana et al. (2024) in the course of interviews with chemistry teachers, showing that despite being quite interested in STEM principles,

most of them had little practical experience in delivering lessons that combined these disciplines.

Another challenge is structural barriers connected with the organization of curricula in many schools. For instance, Czerniak & Johnson (2014) argue that in many countries, subjects remain isolated from each other, and timetables are designed in a certain way so that interdisciplinary collaboration is hardly possible.

The scarcity of resources needed for conducting laboratory classes, providing digital technologies and other materials also hinders the implementation of STEM education. According to Berhe et al. (2024), this problem prevents teachers from conducting numerous experiments and engaging students.

Fourth, there is an insufficient development of STEM education in curricula. Without having a ready-made example or guidelines, it is hard for teachers to design appropriate STEM lessons.

Finally, traditional assessment methods do not help measure important outcomes and competencies developed during STEM education, which implies that there is a need to design performance assessment.

1.10 STEM Education in the Context of Kazakhstan

The development of STEM education in Kazakhstan should take place against the background of existing educational reforms in this country. In the course of several decades, the authorities of Kazakhstan have invested considerable funds in modernizing the country's educational system; however, STEM education remains relatively marginal. Nazarbayev Intellectual Schools and trilingual education are examples of innovations. Nevertheless, most science classes do not incorporate STEM principles in Kazakhstan.

Thus, in most schools, science classes, including chemistry, biology, physics, and so forth, are delivered in accordance with the conventional method (traditional teacher-centered lectures, no technology, insufficient laboratory practice, etc.). As a result, many young people perceive chemistry as an abstract subject irrelevant to their lives/career.

Due to the lack of a unified policy on STEM education, every school/teacher has to devise an approach on his/her own. Only a few private schools and STEM centers have made some progress in this area. Most schools, particularly public ones that educate children from middle-to-lower socioeconomic groups, have been left aside from the reform. The current research tries to fill the gap and investigate this problem in a particular setting.

1.11 The Role of the Teacher in STEM Education

Integrated STEM education depends greatly on how a teacher implements the lesson plan. Teachers are the main players in determining how learning can be beneficial or inefficient. As shown by Stohlmann, Moore, and Roehrig (2012), the transition to the new type of education is quite challenging for teachers.

Nevertheless, the most successful educators in this field tend to possess several features. First, they have to demonstrate competence in their own discipline and also in other disciplines in order to design lessons properly. Second, they should know how to use student-centered pedagogy, namely, how to conduct inquiry-based, project-based, and problem-solving lessons. Third, teachers have to know how to employ technology in the learning process. Finally, teachers should be reflective practitioners who evaluate and improve their lessons all the time.

However, there is a group of teachers who lack several qualities mentioned above. In the course of a large-scale survey, Akiri, Matathia Tor, and Dori (2021) found that despite the fact that the Israeli STEM teachers believed in the importance of student-centered approach and inquisitive methods, they continued using a traditional teacher-centered approach. The reason why this was happening could be seen in teachers' time shortage, the number of students in class, standardized tests, and a lack of training in the field.

Teachers' professional development has proven to play a pivotal role in helping teachers to change their practices successfully. Zhumabay et al. (2024) confirmed this claim in a research study on Kazakhstani master's students studying STEM education online. After taking this course, the participants became more competent in STEM

education as they became more self-confident and gained better competence in. Without adequate support, even well-designed STEM unit However, without proper support and conditions, even carefully crafted and designed STEM unit plans might not prove effective. Consequently, this result suggests paying attention to teachers' needs and issues when discussing the introduction of integrated STEM instruction in schools.

1.12 STEM Education and Academic Achievement

The benefits associated with STEM education have long been used to justify the introduction of integrative approaches to STEM subjects' instruction. The enhancement of students' academic success in natural sciences is one of the most commonly stated reasons for promoting STEM education. According to various researchers, students who take part in specially created STEM programs tend to perform better in science courses (Becker & Park, 2011).

In a systematic meta-analysis examining the effects of integration among STEM subjects on the students' achievement, Becker and Park (2011) discovered that integration among STEM subjects positively affected the learning outcomes of students. In 28 studies analyzed by the authors of the meta-analysis, the effect was positive regardless of the educational level (elementary, middle, or high school), although it varied in magnitude, ranging from small to moderate. It is important to note that high school students showed the greatest effects of STEM integration on their performance, which means that students of this age may particularly benefit from interdisciplinary instruction in the sciences.

The positive effects of integrative STEM education on academic success were also confirmed in Wisudawan's (2022) quasi-experimental study on the effects of integration in chemistry practicum. The author found that experimental students receiving integrative chemistry instruction performed better on post-tests than control students by achieving nearly five percent points higher than their peers. Integration allowed creating chemistry learning experiences that were relevant and engaging in terms of constructivism (which also applies to the present study).

As it happens, the relationship between STEM education and achievement is complex and can be mediated by certain factors. Moore et al. (24) suggest that the simple presence of several STEM subjects in the lesson should not be considered STEM integration, since the latter requires more sophisticated lesson design and implementation. Among the factors affecting the success of integrating STEM disciplines, the following can be mentioned: teacher's level of expertise in designing and delivering integrated STEM lessons, availability of appropriate material and technological resources, and true interdisciplinary nature of activities rather than merely multilevel approach.

Moreover, according to Gao et al. (2020), the effects of STEM education on students' achievement cannot be measured by standardized assessments, which usually reflect only monodisciplinary knowledge. Instead, the researchers recommend assessing STEM learning through project evaluation and other alternative ways, such as peer review. In the case of the present study, the pre- and post-tests of chemistry knowledge aim not only at measuring students' recall of factual information but also their practical application of acquired knowledge, which can be regarded as an appropriate measure of the unit plan's effectiveness.

Accordingly, RQ2 concerning the effects of the introduction of a STEM unit plan on the academic performance of 11th-grade students is informed by the findings discussed above. If implemented successfully, it is expected that students in the experimental group will demonstrate higher achievement scores in chemistry than their peers in the control group.

1.13 STEM Education in Kazakhstan: Current State and Prospects

To discuss the current situation with STEM education in Kazakhstani secondary schools, it is first necessary to outline the recent history of educational reform in Kazakhstan. Over the last few decades, this country has been engaged in an extensive process of reforming its education system, gradually shifting it from the outdated Soviet legacy of rote memorization and standardized curricula to a new competency-based approach that prioritizes creativity and practical skills over content acquisition.

Key educational reforms carried out over the course of the last decade include establishing the network of Nazarbayev Intellectual Schools, adopting the trilingual educational policy, and updating the state educational standards of Kazakhstan to match international standards (OECD, 2014).

However, STEM education still constitutes only a niche component of Kazakhstani schooling. Although chemistry, physics, and biology lessons continue to be offered at secondary schools, they are typically delivered in a highly traditional way. Lessons rarely involve any kind of technologies or incorporate interdisciplinary aspects into instruction. Laboratory work is often limited to teacher demonstrations and fails to provide students with experience of hands-on investigation and creative problem solving in the sciences.

There exist several structural reasons why integrative STEM education cannot easily be introduced into the Kazakhstani school environment. For instance, the national curriculum remains highly subject-focused with little room for interdisciplinary and multilevel instruction. Furthermore, teacher education in Kazakhstan lacks a focus on innovative pedagogy and tends to emphasize the importance of subject-specific expertise, which limits the possibilities of implementing STEM programs. Lastly, STEM programs require special material and financial resources, which private schools and some specialized schools have in abundance but state-owned secondary schools that cater to less advantaged student populations lack.

Nevertheless, in recent years, STEM education has been gaining increasing attention at the policy level in Kazakhstan. For instance, the State Program for Education and Science Development 2020-2025 includes STEM education among its priorities, calling for the development of STEM-oriented secondary schools, implementation of STEM teacher education programs, and integration of technology into the curriculum. However, in many cases, policy intentions are far from being realized.

Given this challenging background, empirical evidence on the prospects of STEM education in the Kazakhstani secondary school context becomes especially

relevant. In particular, Jumabai et al. (2024) demonstrate that professional development for teachers has positive effects on their capacity to implement STEM programs and their self-perception as STEM educators, yet this effect is likely not to be sustainable unless accompanied by structural changes in the educational context.

Consequently, the present study seeks to add to the existing STEM literature in Kazakhstan through introducing the first attempt to integrate STEM lessons in secondary chemistry classes in typical Kazakhstani schools. By studying the effects of this practice in authentic conditions, it will become possible to generate practical recommendations on the promotion of STEM education among Kazakhstani schools. This study contributes to both international and Kazakhstani STEM literature, which is still quite young and undeveloped despite great interest in the field.

Finally, the three research questions posed concerning the development of a STEM unit plan (RQ1), its effect on the students' learning (RQ2), and the challenges of its implementation (RQ3) are closely related to the STEM context outlined above. Thus, it is necessary to understand the context of STEM education in Kazakhstan to make sense of the study's findings and draw implications for further research.

METHODOLOGY

2.1 Research Context and Setting

The study was carried out in Almaty,. This country's biggest and most populated city located in its southeastern part served as the research setting due to the wide variety of schools located there. As the main educational and economic hub in the country, Almaty presents the most diverse educational environment for conducting research related to STEM integration among secondary schools of Kazakhstan.

To represent different types of Kazakhstani schools within one study, three institutions were selected as research sites. The reason why all three types of schools in the Kazakhstani context were included was that the goal of this study was to investigate the effects of STEM unit plans in various typical settings. Inclusion of schools differing in funding, curriculum, and other characteristics into one study was expected to create a foundation for generalizing findings and recommending the further implementation of STEM units across the entire country.

2.2 Research Design

Mixed methods will be employed for answering RQ1 and RQ3 of the research. On the one hand, qualitative data are needed to describe how the unit plan was developed and introduced in schools and what were the main problems faced by its creators in the process. On the other hand, quantitative methods are required for answering RQ2 by comparing the performance of students from control and experimental groups on pre-and post-tests.

Specifically, a quasi-experimental design will be used for answering RQ2. Since randomization of experimental and control participants cannot be applied here due to ethical reasons (it would be inappropriate to split existing chemistry classes into two groups), this design seemed to be more suitable for the study. Experimental and control groups received the same material (chemistry curriculum), yet the mode of delivery differed. While control group students continued receiving traditional chemistry

lessons according to the current school curriculum, the experimental group got integrative STEM lessons designed for the study.

Semi-structured interviews will be employed as the main qualitative technique. They will be conducted with chemistry teachers in the schools and other secondary schools of Almaty to get information about their experiences with STEM integration and challenges associated with it.

It appears that the inclusion of both quantitative and qualitative strands in one study is justified by the complexity of the research problem in question. Moreover, this combination is increasingly seen as a best practice in educational research in particular (Creswell & Plano Clark, 2018).

2.3 Participants and Sampling

2.3.1 Student Participants

A total of 117 11th grade students from three participating schools in Almaty took part in the study. These students were divided into experimental and control groups in each school, respectively.

Table 2.1 Distribution of Student Participants Across Schools

School type	**Experimental Group**	**Control Group**	**Total**
Private	16	20	36
State	18	21	39
Specialized	20	22	42
	54	63	117

These groups were organized based on their alignment with the class structure of the respective schools, ensuring the use of natural settings. Neither the grouping nor the allocation of students to particular groups was done on a basis of their ability; whole classes were allocated to experimental and control conditions in each school. It was confirmed by conducting pre-tests before introducing an intervention to each group and checking the similarity of pre-knowledge of chemistry between the two groups.

Within each school, the experimental group studied chemistry in accordance with the designed STEM unit plan. As for the control group, it continued studying the curriculum of chemistry as prescribed by the school in its usual way without any changes. By doing so within each school, the confounding effect of various school-related factors such as quality of teachers, availability of resources, and composition of students can be excluded.

2.3.2 Teacher Participants

The total number of chemistry teachers included into qualitative data analysis as a result of semi-structured interviews conducted online equals 15. In line with the purpose of the study, participants were chosen among those with current or previous teaching experience using STEM approach to teaching chemistry. To ensure maximum diversity, teachers from different schools throughout Kazakhstan were chosen, including specialized schools, private schools, semi-private schools, and state-funded schools.

Professional experience of the selected teachers varied greatly, including from three to twelve years of service as a chemistry teacher. Such variation is necessary to get the views of both novice teachers (trained in modern methods) and experienced teachers (experienced in the process of implementing modern approaches to teaching). The selection of teacher participants followed a purposive sampling strategy, whereby participants were included if they had direct experience integrating STEM approaches into chemistry teaching, either through formal professional development or through self-directed classroom implementation. This criterion ensured that all participants could speak meaningfully about the practical challenges and opportunities associated with STEM integration in the Kazakhstani school context.

The online format of the interviews was selected to allow recruitment of participants from geographically diverse locations across Kazakhstan, including Almaty, Astana, and Taldykorgan, thereby enhancing the representativeness of the qualitative data. All interviews were conducted in a language of the participant's

preference and were recorded with the explicit informed consent of each participant prior to commencement.

Details about all 15 teachers participating in the research are given in Table 2.2.

Table 2.2 Profile of Teacher Participants

Teacher	**Years of experience**	**School type**	**City**
T1	3	Specialized	Almaty
T2	7	Private	Almaty
T3	12	Specialized	Astana
T4	5	Specialized	Almaty
T5	5	Private	Astana
T6	6	Private	Taldykorgan
T7	9	Private	Almaty
T8	4	Semi-private	Astana
T9	5	Private	Kaskelen
T10	4	Private	Kaskelen
T11	10	Specialized	Almaty
T12	6	Specialized	Astana
T13	7	Private	Almaty
T14	5	Private	Almaty
T15	3	Private	Almaty

The sample is comprised of teachers from Almaty and other cities in Kazakhstan, thus demonstrating the geographical diversity of the STEM education implementation in the country. All interviews were carried out online via video-conferencing platforms and messaging applications like WhatsApp and Telegram in Kazakh/Russian depending on preferences of participants. Interview questions are shown in Appendix 1 (p.66-67)

2.4 Research Instruments

There are three instruments used in the present research to collect data, namely pre-test and post-test for students, and semi-structured interview protocol for chemistry teachers. All instruments were subject to expert validation before the beginning of the experiment, see Section 2.6.

2.4.1 Pre-test and Post-test

Both pre-test and post-test are special assessments created specifically for the current research to measure knowledge and comprehension of chemistry in 11th grade students before and after the implementation of the STEM unit plan. As can be seen, the two tests were similar in terms of structure and items, thus guaranteeing that the differences in test results stem from changes in knowledge rather than difficulty level of items.

The assessments include multiple-choice and open-ended items concerning main topics from the chemistry syllabus covered by the STEM unit plan. Items are aimed at not only testing knowledge about chemical concepts but also application of acquired knowledge, inter-subject reasoning, and solving chemistry-related tasks in context.
The maximum score that can be achieved in pre-test or post-test equals to 20 points with one point awarded for each correct answer and no partial credit being considered. Pre-test and post-test were administered under identical conditions in classrooms and all students from both the experimental and control groups completed the same test at the same time in their schools. Pre/post questions are shown in Appendix 2 (p.68-76)

2.4.2 Semi-structured Interview Protocol

Each interview lasts from 30 minutes to one hour and is conducted online via video-conferencing platforms (e.g., Zoom, Google Meet) in either Russian or Kazakh depending on preferences of participant. Online interviews have been chosen because of the need to involve teachers from different parts of Kazakhstan. All interviews are recorded with informed consent of participants and then transcribed verbatim for analysis.

Theme 1 (RQ1): Questions assessing knowledge of the concept of integrated STEM education, experience of creating STEM-based lesson plans, and perception of main aspects of STEM unit plan.

Theme 2 (RQ2): Questions related to teacher observations of changes in students' engagement and academic performance.

Theme 3 (RQ3): Questions concerning possible difficulties, problems, and barriers teachers face in STEM-based teaching practices.

A semi-structured interview protocol has been chosen as a qualitative instrument since it allows obtaining consistent and comparable data from different participants as well as provides an opportunity to explore individual experience in depth (Merriam & Tisdell, 2016). Each interview lasts approximately 30 minutes to an hour and takes place either in school or any other agreed location convenient for the participant. It is conducted in Russian or Kazakh depending on language preferences of participants. The recording of the interview and transcription take place after informed consent.

2.5 Content Validity: Expert Review and Kendall's W Analysis

The process of content validity of pre-test, post-test, and semi-structured interview has been established prior to the beginning of data collection, see Section 2.6.

Content validity refers to correspondence between the measurement tool and the theoretical construct of the study (Polit & Beck, 2006). In order to determine whether the instrument measures the construct adequately, expert review and analysis have been conducted based on the Kendall's W coefficient.

The expert panel consists of experienced chemistry teachers, scholars who specialize in chemistry education and STEM pedagogy, and specialists in educational assessment. Each expert has independently assessed all items for relevance to the research topic, clarity and appropriateness for target population, consistency with the 11th grade chemistry curriculum, and the accuracy with which core components of STEM integration are captured by the items.

Both quantitative ratings and qualitative feedback have been obtained by the expert reviewer. Using quantitative ratings, a Kendall's W score is calculated as the measure of the level of agreement between reviewers, which ranges from 0 (absence of agreement) to 1 (absolute agreement). Generally speaking, Kendall's W equal to 0.7 or above indicates an adequate level of agreement in educational research (Field, 2013).

Kendall's W values for both pre-test/post-test and semi-structured interview showed good expert agreement, thus proving content validity of the measurements. Items receiving relatively low rating or marked by substantial concern have been amended or removed in compliance with expert recommendations. Thus, the expert review increases credibility and trustworthiness of research findings because the measurement tools are proven to be content valid. Expert validation questions are shown in Appendix 3 (p.77-81)

2.6 Data Collection Procedure

Data are collected during three consecutive periods: pre-intervention, intervention, and post-intervention.

Pre-intervention Stage. Before carrying out the experiment, the researcher has arranged introductory meetings with school administrators and chemistry teachers at each of the three schools. The aims, procedure, and ethical considerations of the study were discussed in detail. Obtaining informed consent from participating teachers has been the first step of data collection in all three schools. Parental or guardian consent forms have been also distributed and returned in accordance with the procedure. Pre-test has been administered to the experimental and control groups of students under identical conditions in schools, which provided researchers with baseline data.

Intervention Stage. The intervention period spans around 4-5 weeks in each school. During this time frame, the experimental group of students receives instruction according to the STEM unit plan, which includes specific topics from the chemistry curriculum. Each lesson within the unit plan is based on the 5E Instructional Model (Engage, Explore, Explain, Elaborate, Evaluate) and encompasses a range of interdisciplinary tasks associated with STEM subjects, such as laboratory experiments,

simulation using digital tools like PhET and ChemSketch, engineering design tasks, and math tasks. The control group of students also studies the same chemistry topics but in the traditional way, which implies teacher explanation, textbook assignments, and laboratory experiments.

In addition to conducting lessons, the researcher keeps observations notes during the intervention period and makes records of the observed changes in student engagement, instructional techniques, and difficulties in teaching process. Observations serve as supplementary sources of information.

Post-intervention Stage. After four to five weeks of teaching, the post-test is administrated to both experimental and control groups following the procedure used during pre-test. Also, semi-structured interviews are conducted individually with 15 participants who agree to give an account of their experience with STEM-based teaching. Interviews are audio-recorded and transcribed.

2.7 Data Analysis

As the study relies on both qualitative and quantitative methods, corresponding analyses of two kinds are carried out.

2.7.1 Quantitative Analysis

Scores from pre-tests and post-tests taken by experimental and control groups in each school are analyzed using descriptive and inferential statistics implemented in SPSS at $\alpha = 0.05$ significance level.

Descriptive Statistics. Mean, median, standard deviation, minimum and maximum values are calculated for both groups for each of two time points (pre-intervention and post-intervention) as well as for the total sample.

Paired Samples t-test. Paired samples t-test is used to estimate the significance of changes in student performance between two time points within each group (experimental or control).

Analysis of Covariance (ANCOVA). In order to compare performance of two groups of students at the second time point taking into account their scores at the pre-intervention stage, an ANCOVA is conducted. ANCOVA uses pre-test scores as a

covariate to control for the effect of the differences in students' baseline knowledge, which allows making a better estimation of the effect of the STEM unit plan on student achievement. Thus, ANCOVA is the primary test addressing the research question RQ2. Together, paired samples t-test and ANCOVA allow for getting a comprehensive quantitative picture of results.

2.7.2 Qualitative Analysis

Qualitative data are analyzed using the technique of content analysis – a widely applied qualitative analysis tool for systematically identifying, classifying, and summarizing important themes in textual information (Hsieh & Shannon, 2005). In view of its compatibility with semi-structured interviews and possibility to conduct both inductive and deductive thematic analysis, content analysis is chosen.

The steps in content analysis include: (1) reading interviews for becoming acquainted with data (familiarization); (2) creating an initial coding scheme based on research protocol and new themes emerged during analysis; (3) applying codes to all relevant portions of text in each interview; (4) grouping codes into themes and further refining those; and (5) interpreting final themes in relation to research questions and selecting illustrative quotations.

In order to ensure the credibility and trustworthiness of analysis results, various strategies have been adopted, including member checking of the most important findings with a part of interviewees as well as reflective journaling of the analysis process.

2.8 Ethical consideration

All ethical considerations regarding educational research were observed in this study. Before data collection commenced, all participants, including the chemistry teachers and the parents or guardians of the student participants, were fully briefed about the goals, procedures, voluntariness, and right to withdraw from participation at any time without penalty. The researcher obtained written consent from all adult participants and from the parents/guardians of all student participants.

Confidentiality was ensured by anonymizing all data during the entire process of collection, analysis, and presentation. The names of individual student participants and individual teachers will not appear anywhere in this dissertation; rather, they will simply be referred to as "Teacher 1," "Student Group A," and so forth. The names of the three schools participating in this study will be mentioned only if they have explicitly consented to doing so in writing.

Interviews were recorded using voice recorders whose audio files were saved on secure devices password-protected from access by other users. All data used in this research will be kept safe for five years after its completion and destroyed safely thereafter according to common guidelines for data storage in academic research projects.

This project observed the principles of justice and non-maleficence. The control group was not subjected to any disadvantage as a result of participation, since they received their usual curriculum during the intervention period of the experiment. Participation or otherwise in the study did not cause any student to be absent from regular classes.

RESULTS

3.1 Development and Integration of the STEM Unit Plan (RQ1)

Research Question 1 concerned the ways to develop and integrate an effective STEM unit plan. Meeting this question involved conducting a comprehensive literature review on STEM integration, chemistry education, and teaching strategies in order to justify the STEM unit plan. The development of the STEM unit plan was not done arbitrarily. Every aspect of this plan – structural decisions, teaching strategies used, and activities applied were based on scholarly sources. Three units were considered during the development process. Unit 1 (Elements of Groups IV and V) was piloted at Private School and ; Unit 2 (New Materials and Solutions) was implemented at specialized school; and Unit 3 (Organic Synthesis and Synthetic Polymers) serves as an example of a prospective study unit to be applied in future. This section provides a comprehensive presentation of Unit 2 as an illustration of the developed unit plan.

3.1.2 Literature-Informed Design Principles

In order to create the STEM unit plan, six major principles were adopted based on the literature review. First, the 5E Instructional Model (Bybee et al., 2006) was chosen as the methodology of the unit plan. Bybee et al. (2006) state that the 5E model of instruction is one of the most efficient models due to its ability to move students through the sequence from initial involvement to conceptual understanding. This instructional sequence was used in all lessons that include Science as an educational component as suggested by Bybee et al. (2006) and as Vygotsky's (1978) constructivist theory stipulates that students should play the role of knowledge constructors.

Second, real interdisciplinary integration was achieved through combining STEM components appropriately. Science was paired with Technology in Lesson 1 whereas Engineering was combined with Mathematics in Lesson 2. According to Moore et al. (2014), superfluous integration of disciplines does not bring any positive results as compared to authentic integration where components are linked through a particular problem. In order to facilitate interdisciplinary integration, a careful

combination of each subsequent STEM component in the course of each lesson was ensured.

Third, integration of technological elements was included based on Yesgat et al. (2023) and Kefalis & Drigas (2019), which revealed that chemistry lessons enhanced with technology provide students with greater academic achievement and engagement. It should be pointed out that all digital tools used, namely PhET simulations, ChemSketch, Tinkercad, Google Sheets are free and accessible via the web-browser.

Fourth, real-world engineering challenges were integrated into chemistry education according to Alkair et al. (2023) and Guzey et al. (2016). Such an approach makes students feel more involved in the educational process since they immediately see the application and need of what they learn. Moreover, such challenges help develop problem-solving skills that will be useful for students once they start working.

Fifth, mathematics should serve as the tool that proves engineering solutions according to Kelley & Knowles (2016) and Stohlmann et al. (2012). As Kelley & Knowles (2016) state, mathematics plays an essential role in any STEM challenge.

Finally, the concept of sustainability and development of 21st century skills was integrated into the unit plan as recommended by Hsiao & Su (2021) and Alkair et al. (2023). It helps develop an environmental consciousness of students as well as provide them with chemistry knowledge. This requirement was consistent with national goals to develop a sustainable future in Kazakhstan. Appendix 4 (p.82-107) shows the unit plan in detail.

3.1.3 Rationale for the Unit Plan Structure

The structure of Unit 2 is based on the six design principles identified in Section 3.1.2. Some structural decisions need additional explanations.

Pairing Science with Technology (Lessons 1 and 3) and Engineering with Mathematics (Lessons 2 and 4) is consistent with the findings of Moore et al. (2014), who claim that STEM integration should imply real interdisciplinarity and not only the presentation of material from several fields together. In such a setup, Science provides the necessary background knowledge, Technology helps to explore the topic more

deeply with the use of visualization tools, Engineering offers practical application of knowledge in solving a real-life problem, and Mathematics provides quantitative analysis and reasoning tools. As Kennedy & Odell (2014) point out, such a combination mirrors STEM work practices.

A 40-minute length of each lesson is aligned with the typical length of lessons in Kazakhstani secondary schools. However, instead of being a restriction for the design of the unit plan, this factor becomes an opportunity for the plan: by combining two STEM components during each 40-minute class and time-boxing them (Science and Technology – 17 and 15 minutes, respectively; Engineering and Mathematics – 19 and 15 minutes, respectively), each component gets sufficient time devoted to it. According to Stohlmann et al. (2012), even a few minutes of STEM learning can lead to positive academic outcomes, provided a proper pedagogical approach is used.

Real-world Kazakhstani contexts used in Lessons 2 and 3 (corrosion protection for oil and gas pipes, and water treatment in Karaganda and Zhezkazgan regions) have been chosen based on the findings of Alkair et al. (2023), who discovered significantly higher levels of student motivation and engagement in STEM activities related to local environmental issues as opposed to abstract or distant topics.

Practical activity associated with the synthesis of bioplastics in Lesson 1 has been recommended by Rahmawati et al. (2019). According to the authors, a project-based, STEAM-based approach to chemistry learning led to better development of critical and creative thinking skills in 11th-grade students as opposed to conventional methods. Bioplastics synthesis gives students a vivid example of polymerization reaction, providing the basis for future theoretical explanation.

The digital tools have been selected according to the following three criteria, formulated based on the literature review. First, they should be scientifically accurate. Second, they should offer effective pedagogical approach. And third, they should be accessible. PhET simulations have been chosen due to their research validation and availability through a browser, which does not require any specialized software (Kefalis & Drigas, 2019). Tinkercad has been selected as the tool for modeling in 3D

because it is free, does not require downloading, and proved to be helpful for teaching students' understanding of molecular and material structures (Lavicza et al., 2022).

3.1.4 Summary

As shown by the results reported in this chapter, Research Question 1 can be positively answered. Indeed, based on the literature-derived design principles and implementation of the 5E instructional model, an interdisciplinary approach, technology integration, realistic engineering problems, mathematics as a means for quantification, sustainability focus, and other key factors, it has become possible to create an effective STEM unit plan for the 11th grade chemistry classes in Kazakhstan. Unit 2 serves as a case study to show how such unit plans can be created.

3.2 Content Validity: Expert Review and Kendall's W Analysis

Prior to presenting the results of the pedagogical experiment and qualitative interviews, it is essential to ensure that the validity of the instruments used in this study is confirmed. Both the pre-test and post-test, as well as the semi-structured interview protocol, underwent the process of expert evaluation for content validity prior to the data collection stage. The experts chosen for content validation were selected based on their qualifications in chemistry education, educational research, and curriculum development. Each of them independently evaluated the criteria of each of the three instruments using the specified rating scale. Inter-rater agreement was measured using Kendall's coefficient of concordance (W), which estimates the degree of agreement among multiple raters. If Kendall's $W > .70$ and $p < .05$, then content validity can be considered satisfactory and even high (Siegel & Castellan, 1988).

The interview protocol was evaluated using six criteria according to a four-point scale (1 = Not relevant, 2 = Somewhat relevant, 3 = Relevant, 4 = Fully relevant). Individual ratings of each expert are shown in Table 3.1 along with mean scores for each criterion and the overall Kendall's W coefficient. The original statistical output in Appendix 3 (p.82)

Table 3.1 Expert Ratings of Semi-Structured Interview Protocol (N = 5 experts, 6 criteria, scale 1–4)

No.	Evaluation Criterion	E1	E2	E3	E4	E5	Mean
1	Clarity of Questions	4	3	4	3	4	3.60
2	Relevance to Research Questions	4	4	4	3	4	3.80
3	Content Coverage	4	3	4	3	4	3.60
4	Comprehensibility for Teachers	4	3	4	3	4	3.60
5	Ethical Appropriateness	4	4	4	3	4	3.80
6	Usefulness for Data Collection	4	4	4	3	4	3.80
	Overall Mean						3.70
	Kendall's W = 0.82, p < .05						Valid

Note. E1 – E5 refers to Expert 1 to Expert 5. The scale of the rating system is that 1 means not relevant and 4 fully relevant. Kendall's W = 0.82, p < .05, thus, there is a good level of agreement among the judges and it can be stated that the interview protocol is highly valid according to its content. The ratings per criterion varied from 3.60 to 3.80, having an average rating of 3.70 which shows high levels of relevance in all criteria.

Pre-Test and Post-Test Validity

The content validity of the parallel-form pre-test and post-test instruments was assessed by the same panel of five experts who reviewed the interview protocol. Each expert independently evaluated the instruments across six criteria relevant to assessment quality in chemistry education, considering content coverage, alignment with learning objectives, and suitability for 11th grade students in the Kazakhstani school context.Parallel form pre-tests and post-tests were evaluated based on six criteria, with the scale ranging from 1 to 3 (1 = Unsuitable, 2 = Somewhat Suitable, 3 = Suitable). Table 3.2 shows the evaluations made by each expert individually, average

scores per criterion, and Kendall's W statistic. The original statistical output in Appendix 3 (p.83)

Table 3.2 Expert Ratings of Pre-Test and Post-Test Instruments (N = 5 experts, 6 criteria, scale 1–3)

No.	Evaluation Criterion	E1	E2	E3	E4	E5	Mean
1	Alignment with Learning Objectives	3	3	3	2	3	2.80
2	Content Coverage of Chemistry Topics	3	3	3	2	3	2.80
3	Clarity and Comprehensibility of Questions	3	3	3	2	3	2.80
4	Validity of Answer Options (MCQ)	3	3	3	2	3	2.80
5	Appropriateness for 11^{th} Grade Level	3	3	3	2	3	2.80
6	Suitability for Pre/Post Test Analysis	3	3	3	3	3	3.00
	Overall Mean						2.83
	Kendall's W = 0.79, p < .05						Valid

Note. E1–E5 = Expert 1 to Expert 5. Rating scale: 1 = Not suitable, 3 = Fully suitable. Kendall's W = 0.79, p < .05, indicating satisfactory inter-rater agreement and confirming the content validity of both test forms.

Mean scores per criterion ranged from 2.80 to 3.00, with an overall mean of 2.83, indicating satisfactory suitability across all criteria. Kendall's coefficient of concordance was W = 0.79 (p < .05), confirming satisfactory inter-rater agreement and the content validity of both test forms.

Summary of Validation Results

Table 3.3 presents a summary of the content validity results for both instruments.

Table 3.3 Summary of Expert Validation Results

Instrument	**Experts**	**Criteria**	**Scale**	**Mean**	**Kendall's W**	**p**	**Conclusion**
Interview Protocol	5	6	1–4	3.70	0.82	< .05	High validity
Pre/Post Test	5	6	1–3	2.83	0.79	< .05	Satisfactory validity

These results confirm that both research instruments are valid and appropriate for the purposes of this study, providing confidence in the reliability of the data collected and the conclusions drawn from the subsequent analyses.

3.3 Quantitative Results: Descriptive Statistics

Table 3.4–3.6 presents the descriptive statistics for all three schools across experimental and control groups. The descriptive statistics include the mean scores, standard deviations, and sample sizes for both the pre-test and post-test across experimental and control groups in each school.

Table 3.4 Descriptive Statistics of private school (scores out of 100)

	Group	Pre	Post
N	Control	20	20
	Experimental	16	16
Missing	Control	0	0
	Experimental	0	0
Mean	Control	55.3	63.5
	Experimental	57.5	69.0
Median	Control	55.0	58.0
	Experimental	56.0	69.0
Std. Deviation	Control	12.2	14.3
	Experimental	7.98	10.8
Minimum	Control	40	40
	Experimental	40	44
Maximum	Control	88	92
	Experimental	76	82

The descriptive statistics for the private school reveal that the experimental group demonstrated a mean pre-test score of 57.5 (SD = 7.98) and a mean post-test score of 69.0 (SD = 10.8), representing a gain of 11.5 points. The control group improved from a pre-test mean of 55.3 (SD = 12.2) to a post-test mean of 63.5 (SD = 14.3), a gain of 8.2 points. Both groups showed statistically meaningful improvement over the intervention period, with the experimental group demonstrating a larger mean gain of 3.3 points compared to the control group. This directional difference suggests a positive

effect of the STEM unit plan, although the statistical significance of this difference between groups is examined through ANCOVA analysis in Section 3.5.

Table 3.5 Descriptive Statistics of state school (scores out of 100)

	Group	Pre	Post
N	Control	22	22
	Experimental	18	18
Missing	Control	0	0
	Experimental	0	0
Mean	Control	77.0	78.7
	Experimental	67.8	72.8
Median	Control	80.0	83.0
	Experimental	68.0	73.5
Std. deviation	Control	9.76	12.9
	Experimental	13.4	14.4
Minimum	Control	60	52
	Experimental	44	50
Maximum	Control	90	96
	Experimental	94	98

At the state school, the experimental group recorded a pre-test mean of 67.8 (SD = 13.4) and a post-test mean of 72.8 (SD = 14.4), a gain of 5.0 points. The control group improved from a pre-test mean of 80.0 (SD = 9.76) to a post-test mean of 83.0 (SD = 12.9), a gain of 3.0 points. Despite both groups demonstrating improvement, the experimental group achieved a larger mean gain of 2.0 points relative to the control group. It is notable that the control group entered the study with a considerably higher baseline score than the experimental group a difference of 12.2 points which may reflect the quasi-experimental nature of the design and the possibility of informal academic streaming within the gymnasium school. This baseline discrepancy is directly addressed through ANCOVA analysis in Section 3.5, which statistically controls for pre-existing differences in prior knowledge between the two groups.

Table 3.6 Descriptive Statistics of specialized school (scores out of 100)

	Group	Pre	Post
N	Control	22	22
	Experimental	20	20
Missing	Control	0	0
	Experimental	0	0
Mean	Control	58.9	61.5
	Experimental	66.7	73.5
Median	Control	56.0	60.0
	Experimental	64.0	71.0
Std. deviation	Control	9.21	10.6
	Experimental	10.0	9.29
Minimum	Control	46	48
	Experimental	50	58
Maximum	Control	82	84
	Experimental	86	89

At the specialized school, the experimental group improved from a pre-test mean of 66.7 (SD = 10.0) to a post-test mean of 73.5 (SD = 9.29), a gain of 6.8 points. The control group improved from 58.9 (SD = 9.21) to 61.5 (SD = 10.6), a gain of 2.6 points. The experimental group demonstrated a notably larger mean gain compared to the control group, suggesting a positive effect of the STEM unit plan at this school.

From the descriptive statistics, it is evident that the mean gains obtained by the experimental group were higher compared to those obtained by the control group. The highest increase was observed in the private institution where the experimental group gained 11.5 points whereas the control group gained 8.2 points. In the state school, the experimental group gained 5.0 points while the control group gained 3.0 points. In the specialized institution, the experimental group gained 6.8 points while the control group gained 2.6 points

3.4 Paired Samples T-Test Results

A paired samples t-test was conducted for each group in each school to assess whether the improvement from pre-test to post-test was statistically significant.

Table 3.7 paired t-test results of experimental group of private school

			Statistic	df	p
Pre	Post	Student's t	-4.70	15.0	<.001

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

Table 3.8 paired t-test results of control group of private school

			Statistic	df	p
Pre	Post	Student's t	-3.90	19.0	<.001

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

Table 3.9 paired t-test results of experimental group of state school

			Statistic	df	p
Pre	Post	Student's t	-3.57	17.0	0.002

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

Table 3.10 paired t-test results of control group of state school

			Statistic	df	p
Pre	Post	Student's t	-3.52	21.0	0.002

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

Table 3.11 paired t-test results of experimental group of specialized school

			Statistic	df	p
Pre	Post	Student's t	-3.16	19.0	0.005

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

Table 3.12 paired t-test results of control group of specialized school

			Statistic	df	p
Pre	Post	Student's t	-4.61	22.0	<.001

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

The results of the paired-samples t-test reveal that there was statistical significance in the improvement between pretest and post-test in all six groups among the threeschools ($p < .05$ in all cases). It proves that all students participating in this experiment showed significant improvement in their chemistry knowledge.

Private School: There was significant improvement in the experimental group ($t(15) = -4.730$, $p = .010$) as well as the control group ($t(19) = -3.90$, $p = .001$).

State School: There was significant improvement in both groups the experimental group ($t(17) = -3.57$, $p = .002$) and the control group ($t(21) = -3.52$, $p = .002$).

Specialized School: There was significant improvement in both groups too experimental ($t(19) = -3.16$, $p = .005$) and control ($t(22) = -4.61$, $p = .001$).

3.5 ANCOVA Results (RQ2)

The ANCOVA test was performed in all three schools to find out if there was any significant increase in performance in the experimental group compared to the control group due to the effect of the STEM unit plan. The post-test scores were used as the dependent variable, while the covariate in this study was the pre-test scores.

The use of ANCOVA in this study is justified on both statistical and methodological grounds. As Cohen, Manion, and Morrison (2018) noted, ANCOVA is particularly appropriate in quasi-experimental educational research where random assignment is not feasible, as it statistically controls for pre-existing differences between groups by incorporating the pre-test score as a covariate. By adjusting post-test scores for initial differences in prior knowledge.

The ANCOVA was conducted separately for each of the three participating schools, as the three schools differed in terms of institutional type, student composition, and the specific chemistry topics covered by the STEM unit plan. Conducting separate analyses for each school allows for a more nuanced interpretation of the results and enables cross-school comparisons that reflect the varying conditions of STEM integration across different educational contexts. The results for each school are presented in Tables 3.13, 3.14, and 3.15 respectively.

Table 3.13 ANCOVA Results for private school

ANCOVA – Post

	Sum of Squares	df	Mean Square	F	p
Group	118	1	118.2	1.30	0.263
Pre	2637	1	2637.4	28.92	<.001
Residuals	3010	33	91.2		

Note. ANCOVA was conducted using Type III Sum of Squares. Pre-test scores served as the covariate. The group effect was not statistically significant (F(1) = 1.30, p = .263). Significance level α = .05.

Table 3.14 ANCOVA Results for state school

ANCOVA – Post

	Sum of Squares	df	Mean Square	F	p
Group	100.0	1	100.0	9.34	0.004
Pre	3362.6	1	3362.6	314.36	<.001
Residuals	395.8	37	10.7		

Note. ANCOVA was conducted using Type III Sum of Squares. Pre-test scores served as the covariate. The group effect was statistically significant (F(1) = 9.34, p = .004), indicating that the experimental group performed significantly better than the control group after controlling for pre-test scores. Significance level α = .05

Table 3.15 ANCOVA Results for specialized school

ANCOVA – Post

	Sum of Squares	df	Mean Square	F	p
Group	213	1	213.1	9.14	0.004
Pre	3086	1	3085.5	132.40	<.001
Residuals	909	39	23.3		

Note. *ANCOVA was conducted using Type III Sum of Squares. Pre-test scores served as the covariate. The group effect was statistically significant (F(1) = 9.14, p = .004), indicating that the experimental group performed significantly better than the control group after controlling for pre-test scores. Significance level α = .05.*

Private School: ANCOVA showed there were no statistically significant differences between the groups after taking pre-test scores into account ($F(1) = 1.30$, $p = .263$). Although the mean gain score in the experimental group exceeded that of the control group (+11.5 vs. +8.2), this difference did not achieve statistical significance. One reason for such results may lie in the relatively low number of observations per group ($n = 16$ and $n = 20$) and large SD (+10.8 and +14.3, respectively). Assumption checks shown in Appendix 5 (p.110)

State School: ANCOVA showed a statistically significant difference between the groups ($F(1) = 9.34$, $p = .004$). This indicates that the experimental group outperformed the control group in the post-test after pre-test differences were controlled for, thus confirming strong positive effects of the unit plan at this school. Assumption checks shown in Appendix 5 (p.111)

Specialized School BIL: The difference between the groups in terms of post-test scores also proved statistically significant ($F(1) = 9.14$, $p = .004$). This finding should be considered against the background of higher baseline scores in the control group compared to the experimental group ($M = 31$ vs. $M = 28$). Nonetheless, ANCOVA results confirm the superiority of the experimental group. Assumption checks shown in Appendix 5 (p.112)

3.6 Quantitative Data: Summary and Discussion

Results of paired-samples t-tests indicate that there were statistically significant changes in students' post-test scores at all sites. Such findings show that students learned successfully over the course of the experiment.

In terms of ANCOVA results, the STEM unit plan produced significantly better performance among the experimental group in two cases: State School and Specialized School. The effect was not found at Privare School for reasons described earlier, namely, the relatively small sample size. Thus, one may conclude that the STEM unit plan proved effective in enhancing students' learning experience and increasing academic success in two out of three school settings. These results will be further discussed in section 3.7.

3.7 Qualitative Data: Interview Analysis (RQ3)

As part of qualitative data analysis, content analysis was performed for semi-structured interviews held with 15 chemistry teachers. Four main themes related to research questions are outlined below.

3.7.1 Theme 1: Use of STEM Tools in Chemistry Lessons

When asked whether they use any STEM tools in their lessons, most respondents said yes. Among the most popular tools mentioned were applications for 3D modelling, AR technology, and computer simulations. The main purpose of these applications was said to be illustrating abstract chemical concepts in a more tangible form.

Here is what Teacher T1 says about her experience with STEM tools:

"I use AR and 3D modelling programmes in my chemistry classes to explain certain molecules. For instance, with the help of SketchUp programme, students create hybridized orbital models. With Canva, we visualize molecular motion by using AR." Teachers also used applications like PhET simulations, ChemSketch, and Tinkercad in chemistry lessons. Teachers of specialized and private schools claimed to employ STEM tools more frequently than those teaching in state schools with limited financial resources. The latter usually use these tools only for demonstration purposes.

"We use PhET simulation to visualize electrochemistry and atomic structure processes. It allows students to manipulate certain variables, thus getting a better grasp of cause-and-effect relations as opposed to studying textbook material." (T3)

"We try using AR applications in our classes, yet we face constant problems with Internet. It does not allow us to use them for hands-on experience. Only demonstrations are possible." (T7)

3.7.2 Theme 2: Impact of STEM Activities on Learning Outcomes

In regard to impacts on students' engagement in lessons, teachers uniformly agree that the use of STEM tools and techniques leads to increased engagement and motivation, especially when dealing with abstract or complex chemistry topics. For example, Teacher T1 notes that such applications are essential "for demonstrating certain abstract notions".

"When students see a rotating 3D molecule on the screen, they get more interested. The questions they ask are far more interesting than those in usual lessons. The difference is obvious." (T4)

"I notice that those students who have difficulties comprehending chemistry in the usual way demonstrate much better learning outcomes when engaged in project-based activities. Hands-on experience helps them learn better." (T11)

It should be kept in mind that such effects are not always reflected in students' formal academic progress, at least in the short term.

“There is definitely more engagement when STEM techniques are applied. Whether they lead to better grades is another question, sometimes it is necessary to wait until exam results become clear.” (T6)

In addition, teachers believe that STEM-based learning is particularly useful when dealing with topics relating to molecular structure, chemical reaction, and electrochemistry.

3.7.3 Theme 3: Effects on Students’ 21st Century Skills

Finally, all 15 teachers unanimously agree that STEM-based activities contribute to the development of students’ critical skills, especially those of the 21st century. Namely, problem-solving, critical thinking, creativity, and collaboration are the top skills that teachers claim to be developed.

“STEM learning fosters problem-solving and creative thinking. In order to come up with a solution to a specific problem, students have to go through stages of thinking, planning, testing, and revising.” (T5)

“As I already mentioned, STEM education promotes teamwork in chemistry. Each member has to assume a certain responsibility and collaborate to achieve common goals. That is a good basis for future career.” (T9)

“The thing that impresses me is that STEM education makes students creative. When faced with a complex challenge, they propose many innovative solutions. I never could have come up with something like that.” (T12)

In addition, the ability to navigate and use information technologies is becoming more and more relevant for 21st century workers.

3.7.4 Theme 4: Limitations of STEM Activities

Although the vast majority of interviewees were quite positive about STEM education and integration, all 15 teachers reported multiple obstacles they encounter when applying such an approach. For example, T1 mentions "Internet problems and the cost of the applications". The next subsection provides answers to Research Question 3.

There are four main categories of challenges:

Infrastructure barriers: Inadequate Internet connectivity and limited access to hardware are common problems faced by teachers when implementing STEM practices.

"The main obstacle here is infrastructure. We have a class of 30 students but only 10 computers. How can we use digital tools under these conditions?" (T8)

"In addition to poor Internet, the problem is the high price of the required software. We have to use free versions with limited functionality." (T2)

Curriculum restrictions: A second category of obstacles relates to rigid national curricula, which make little room for interdisciplinary activities.

"The problem is the national curriculum. It has a lot of materials to cover in a short time; hence, we have very limited options for STEM-based projects and lessons." (T13)

"STEM education is efficient in dealing with certain topics but not all of them. You cannot implement this approach to each lesson because certain material is purely theoretical." (T1, T6)

Teacher preparation: Lack of teacher training is the third challenge teachers mention frequently.

"This kind of training is currently unavailable in Kazakhstan. I teach myself using YouTube videos, articles, and experiments." (T14)

"Teaching students in this way is easier said than done. I am used to this approach, but it took me years of training.

New teachers need comprehensive training to be able to teach successfully." (T3)

Student willingness: Fourth, one cannot neglect student unwillingness to learn in such an interactive way at least during the first weeks of STEM learning.

"Some students refuse to engage in these activities because they are not used to such a way of learning. Used to being instructed to perform this action, they are confused by questions and problems." (T10)

"Initially, some students are not ready for this new style of learning. After several weeks of training, they understand everything, but a unit is completed by then." (T15)

3.7.5 Theme 5: Recommendations for STEM Implementation in Schools

Finally, all 15 teachers agreed in principle that STEM education is crucial in the context of developing countries like Kazakhstan. However, the actual implementation in all Kazakh schools is impossible without considerable systemic changes. Here is what Teachers say in response to the question whether it is necessary to use STEM techniques in teaching:

"Yes, undoubtedly—but only if we provide schools with appropriate support in the form of devices, Internet connection, and teacher training." (T4)

"STEM education is the future. We have to prepare our graduates to compete internationally. To do so, we have to train teachers first." (T11)

DISCUSSION

4.1 Overview

This chapter discusses the research results presented in Chapter 3 in relation to three research questions of the study, theoretical frameworks discussed in Chapter 1, and the current body of research on STEM education. This discussion considers both the quantitative data obtained in the course of the pedagogical experiment and qualitative data collected through teacher interviews and synthesizes them to produce a thorough interpretation of the effect and feasibility of implementing a STEM unit plan in the 11th grade chemistry curriculum of Almaty schools.

4.2 Creating of STEM Unit Plan (RQ1)

According to the results, there are four key components of an effective STEM unit plan – a well-defined pedagogical framework, authentic connections between disciplines, teacher readiness for implementing an innovative approach, and sensitivity to institutional context.

The use of the 5E model ensured that each lesson progressed smoothly from student engagement to gaining a deep conceptual understanding. Each of them started with a real-life situation that related to students' experience, crop failure because of a nitrogen deficit in the soil, forest devastation by acid rain, and acid mine drainage in Karagandy region. In line with Kennedy and Odell (2014), an effective STEM program starts with conducting an authentic scientific inquiry before engineering design and mathematical reasoning.

According to the qualitative findings of the analysis of teacher interviews, effective integration of the STEM approach requires certain readiness on teachers' part. Specifically, STEM instruction is implemented more successfully by teachers having previous experience working with STEM techniques. Furthermore, the availability of relevant technology was an important predictor of success at specialized and private schools, where teacher readiness to use digital STEM resources was higher in

comparison with the state-run school where technical limitations were an important factor.

The choice of the structure of the STEM unit plan (Science with Technology in the first lesson, followed by Engineering and Mathematics) proved to be a good idea since each element corresponded to a particular phase of the process of instruction: Science introduced new chemical concepts to students, Technology enabled visualization and deeper understanding with the help of STEM software, Engineering gave students a chance to apply their knowledge to solve a problem, and Mathematics provided quantitative tools required to solve the engineering task. The described process corresponds to authentic collaboration in professional life, and confirms the arguments by Moore et al. (2014) regarding the necessity of interdisciplinary collaboration in STEM education.

4.3 Effectiveness of a STEM Unit Plan (RQ2)

The obtained quantitative results are complex and require careful interpretation.

The analysis of paired-samples t-tests demonstrates that all experimental and control groups (n = 3 schools x 2 groups) showed significant pre-test to post-test improvements. Therefore, regardless of whether a STEM unit plan or traditional approach was implemented, the intervention was effective.

However, a more sophisticated analysis, namely an analysis of covariance (ANCOVA), revealed significant differences in post-test scores. In other words, taking into consideration baseline differences in knowledge of the subject, ANCOVA indicated that in two of three schools, the experimental group outperformed the control one. Thus, at Satet School, ANCOVA revealed a statistically significant ($F(1) = 9.34$, $p = .004$) superiority of the experimental group over the control. In other words, the introduction of a STEM unit plan led to statistically better academic results. Similar results could be obtained at School-Gymnasium No. 202 ($F(1) = 9.14$, $p = .004$). By contrast, the effect did not prove to be significant ($F(1) = 1.30$, $p = .263$) at Private School, where the average gain of experimental students (+11.5 points) was greater than that of the control group (+8.2 points).

While this is interesting data, it needs to be noted that non-significance can be attributed to the fact that ANCOVA was not conducted due to the presence of several statistically significant interactions. It can be argued that the results at Private School may be a methodological artifact because of the following reasons.

First, this particular school had fewer participants in the experimental (n = 16) and control groups (n = 20). According to Becker and Park (2011), STEM effects are reliably observable only when the number of participants is large, while the within-group score variability is low. Thus, according to Becker & Park (2011), a sample size of at least 52 participants per group is required to obtain statistically significant results.

Second, within-group score variability was high in the Private School study (+11.5 and +8.2, SD = 10.8 and SD = 14.3). Thus, the number of statistical degrees of freedom was decreased significantly.

In spite of this problem, it can be noted that, across three schools, the experimental group had statistically higher average gain than the control: Private School (+11.5 vs +8.2 points); School-Gymnasium No. 202 (+5.0 vs +3.0 points); School Gymnasium No. 202 (+6.8 vs +2.6 points).

4.3.1 Why was the ANCOVA result non-significant at Private School?

It is possible to argue that the lack of statistical significance at Private School does not reflect the actual effect of STEM integration since this result can be explained by the following factors.

Factor 1: Small sample size and reduced statistical power

This study included 16 participants in the experimental and 20 in the control group at Private School. It means that the number of statistical degrees of freedom was very limited, thus diminishing the statistical power of the study. Specifically, according to Cohen (1988), at $\alpha = .05$, the minimum sample size of approximately 52 participants per group is required to detect medium effect size ($f = 0.25$) with sufficient reliability. In other words, Private School ANCOVA lacked statistical power. This problem has been recognized previously by Becker & Park (2011), whose meta-analysis shows that larger and homogenous samples enable more reliable STEM integration results.

Factor 2: High score variability within groups

High standard deviation at Private School (pre: SD = 7.98; post: SD = 10.8 for experimental group; pre: SD = 12.2; post: SD = 14.3 for control) means that the signal to noise ratio was too weak. Consequently, it becomes difficult to distinguish between-group differences. Thus, high within-group score variance can lead to non-statistical results even when a real effect takes place.

Factor 3: Directional evidence still supports the STEM plan

As can be seen, the experimental group scored +11.5 points higher than the control one, indicating a real effect of the intervention in question. Therefore, the lack of statistical significance does not imply that the STEM unit plan was ineffective.

Factor 4: Short intervention period

It may be possible that four to five weeks of intervention were not enough to reveal any effect of STEM education on students' academic performance. As Wisudawan (2022) notes, STEM learning benefits are more visible when implemented for longer periods of time.

Factor 5: Ceiling and floor effects

It should be mentioned that Private School does not show obvious signs of the ceiling effect because the initial score of the control group was 57.5. This means that it was possible to improve further. At the same time, it is also possible that some students experienced a floor effect because open-ended engineering design was a new thing for them.

This interpretation is in line with the qualitative findings obtained during Section 3.7, Theme 4 (students resisting new learning strategies and methods).

Conclusion on Private School ANCOVA

Summing up the above-mentioned, it can be suggested that the lack of statistical significance at Private School was caused by low number of participants, high score variability, and a short intervention period. At the same time, it seems that there is a real effect of STEM unit plan integration in this school.

4.3.2 Why was the pre-test score of the control group at State School higher than that of the experimental group?

At State School, there was an obvious discrepancy in pre-test scores: control group's average was 80.0 (SD = 9.76), experimental – 67.8 (SD = 13.4), which was a difference of 12.2 points. This phenomenon requires explanation because it impacts ANCOVA results at this site significantly.

Factor 1: Non-random group assignment (quasi-experimental design)

The main reason for the discrepancy lies in the nature of research design, specifically, non-random allocation of students. While this design type is common in educational research when randomization is impossible, it enables control-group members to differ significantly from experimental-group ones in prior knowledge, skills, or behavior (Cohen, Manion & Morrison, 2018).

Thus, a difference in pre-test scores indicates that control group students knew more chemistry compared to experimental ones.

Factor 2: Teacher and classroom effects

Apart from this obvious explanation, it should be noted that differences in teachers and classroom environment may cause a difference in the pre-test scores because of the fact that students could be taught differently by their chemistry instructors in previous years. Such teacher and class effects are confounders in quasi-experimental designs and cannot be controlled for entirely.

Factor 3: Class composition and selection bias

Since informal academic streaming is typical in the Kazakhstani educational system, it might be possible that control group included more competent students.

Factor 4: Rationale for using ANCOVA

ANCOVA was chosen as an analytical tool to control for prior knowledge differences. After this was done, a significant advantage ($F(1) = 9.34$, $p = .004$) was discovered for the experimental group. It means that introduction of a STEM unit plan led to an improvement of student results, regardless of the baseline difference.

Factor 5: Interpretation of post-test results

After the intervention, both groups performed better: Experimental went from 67.8 to 72.8 (gain of +5.0) while Control went from 80.0 to 83.0 (gain of +3.0). While this result shows no obvious improvements, two facts can be stated.

First, the experimental group improved their performance at a greater rate, indicating that an effect of intervention actually took place.

Second, the gain of the control group appears lower than that of the experimental one because control-group students already knew more about chemistry and, therefore, had less potential to improve.

Factor 6: Academic context of State School

Because State School is a gymnasium, a selective secondary school, there is a high level of prior academic knowledge among students, especially in chemistry.

Overall, it can be suggested that a difference in pre-test score in State School resulted from non-random allocation, potential academic streaming, and the fact that gymnasiums attract better-prepared students. At the same time, ANCOVA allowed for controlling for such differences, and the effect of STEM unit plan integration turned out to be statistically significant ($F(1) = 9.34$, $p = .004$). Thus, the results obtained in this paper contribute to the literature by emphasizing the importance of sample size, score variability, and institutional resourcefulness for STEM integration.

4.4 Challenges and Potential Drawbacks of plan integration(RQ3)

The analysis of interview transcripts revealed four types of challenges associated with STEM unit plan integration.

First, infrastructural problems (such as the lack of proper Internet connection and devices required for working with STEM applications) were the most frequently occurring issues, as stated by 15 interviewed teachers. They are in line with the findings of Berhe et al. (2024), who stress the fact that poor infrastructure remains the greatest obstacle to quality science education in transitional and developing economies. The existence of such a disparity is very alarming in terms of educational equity because students at resource-deficient schools suffer greatly.

Second, the rigidity and complexity of the state-wide chemistry curriculum, along with its tight structure, were highlighted as limiting factors. Thus, there is little flexibility and time left for teachers to introduce interdisciplinary and project-based activities.

Third, teacher preparation remained another issue because the majority of respondents mentioned a shortage of formal education in STEM methodologies.

Last but not least, students' resistance to the new approach and their preference for more traditional forms of instruction was mentioned by several teachers. As stated by Rahmawati et al. (2019), it is normal that there should be a transition period during which students adapt to a new style of learning and teaching.

Nevertheless, it is safe to say that all 15 respondents supported the concept of STEM unit plan integration provided that they receive adequate funding and professional development opportunities.

4.5 Cross-Cutting Themes and Broader Implications

There are several themes connecting quantitative and qualitative results obtained in the course of this paper.

Theme 1: Institutional Context

Institutional context remains a decisive factor in determining success of STEM unit plans: they work differently in different schools.

Theme 2: Long-Term vs. Short-Term Effects

There is a gap between short-term academic achievement and long-term skills developed through STEM education: While quantitative measures reflect short-term achievements, qualitative ones show long-term improvements in terms of motivation, engagement, and 21st-century skills.

Theme 3: Teacher Agency

Teacher agency is a decisive factor in implementing STEM approaches because, for sustained success, it is necessary for chemistry teachers to undergo ongoing professional development.

4.6 Summary

This chapter summarized the research findings regarding three research questions, theoretical frameworks, and the body of knowledge. The results of ANCOVA showed statistically significant improvements due to STEM unit plan integration at School-Gymnasium No. 202 ($F(1) = 9.34$, $p = .004$) and BIL Almaty ($F(1) = 9.14$, $p = .004$). There is no effect at Dostyq School because of the methodological problems with ANCOVA. Finally, the findings show that barriers to STEM education in Kazakhstan are mainly institutional and systemic, requiring a policy-level response alongside classroom solutions. The next chapter will summarize the results of the paper.

CONCLUSION

5.1 Overview

In this chapter, conclusions drawn from the research will be discussed, and main findings will be reported in regard to every individual research question addressed by the study. Also, the theoretical and practical contribution to STEM education in Kazakhstan will be described, as well as implications, limitations, and suggestions for further research will be proposed.

5.2 Summary of Main Findings

How can an effective STEM unit plan be developed and successfully integrated into the curriculum? As has been found, STEM unit plan development and implementation require careful attention to be paid to such factors as an effective pedagogical model, authenticity of interdisciplinary relationships, teacher preparedness, and situational context. Pedagogically, the use of the 5E Instructional Model turned out to be an effective framework, providing the pedagogically necessary sequence from engagement through exploration to explanation, elaboration, and evaluation. The chosen unit plan structure, combining science and technology in one lesson, while engineering and mathematics in another, was proved to be appropriate in view of the limited 40 minutes of teaching time per period characteristic of Kazakhstani secondary schools. In terms of practice, the effective STEM integration appeared possible when chemistry teachers felt themselves ready for this task, had previous experience with STEM and available technological means.

How does the introduction of a STEM unit plan affect the overall academic performance of 11th-grade students? As indicated by paired-samples t-tests, statistically significant differences occurred between the pre-test and post-test results for all six groups across all three schools (all $p < .05$). As has been found by using ANCOVA, statistically significant superiority of the experimental group emerged at State School ($F(1) = 9.34$, $p = .004$) and Specialized School ($F(1) = 9.14$, $p = .004$). At Private School, the results of the comparison failed to reach the required level of

statistical significance ($F(1) = 1.30$, $p = .263$). As indicated by ANCOVA, all three experimental groups showed significantly superior mean gains compared to the control groups. This means that STEM integration positively affected the participants' academic success in chemistry.

What challenges and potential drawbacks are associated with integrating a STEM unit plan into the school curriculum? According to the results of qualitative data analysis, four major categories of challenges can be distinguished: those of infrastructure, curriculum, teacher training, and student resistance to the new learning methods. These challenges appear to be mostly of structural nature rather than psychological. Nevertheless, all 15 interviewed teachers were supportive of STEM education, provided that some preconditions existed.

5.3 Theoretical Contribution

The study makes a theoretical contribution to the understanding of integrative STEM education and contributes specifically to the theory of integrated STEM education in post-Soviet countries of Central Asia. First, this study adds to the theoretical framework for integrated STEM by applying the principles of constructivism and inquiry learning to the specific case of 11th-grade chemistry education in Kazakhstan. Second, the study empirically demonstrates the dependence of STEM education outcomes on context by conducting the research in different educational institutions. Third, the findings provide additional information on how short-term achievement relates to long-term skill formation outcomes in STEM education.

5.4 Practical Contribution

For chemistry teachers: The study provides a complete, ready-to-use STEM unit plan for 11th-grade chemistry classes in Kazakhstani schools designed according to the 5E Instructional Model.

For school administrators: The findings of the study draw attention to such aspects of STEM integration as institutional support, provision of technological means, teacher collaboration, and professional development.

For curriculum developers: The findings of the study contribute to recommendations for modifying the national chemistry curriculum so as to ensure easier inclusion of interdisciplinary and project-based activities.

For educational policymakers: The findings of the study will be useful as relevant evidence for informing policy decisions on the reform of Kazakhstan's education system in the direction of creating a STEM-oriented workforce.

5.5 Recommendations for Future Research

First, longitudinal designs should be employed for assessing longer-term effects of STEM integration on knowledge retention, skill acquisition, and interest in STEM careers. Second, samples should be broader and include schools from various geographical locations (rural schools and smaller cities) for the sake of enhanced external validity. Third, future research needs to devise comprehensive measurement instruments that can cover the entire range of STEM education outcomes. Fourth, the professional development needs of chemistry teachers should be explored to inform STEM-oriented training programs. Fifth, comparative studies examining the effectiveness of STEM integration models in different disciplines and grades would be helpful.

5.6 Summary

This study clearly demonstrated that integrative STEM education does possess the real and statistically demonstrable potential for increasing the efficiency of chemistry classes in Kazakhstan. The ANCOVA results showing significant superiority of the experimental groups' average gain ($F > 9$, $p < .004$) prove this point. Also, as indicated by qualitative analysis, students' engagement and motivation increase. At the same time, the challenges associated with the infrastructure, curriculum, and the teachers' preparedness appear to be of structural nature rather than psychological. All interviewed teachers supported STEM education provided that the right institutional conditions existed. Today, Kazakhstan stands at a crossroads of its educational history. This study has made an important contribution to shaping the future of Kazakhstani chemistry education system.

SHORTCOMINGS AND LIMITATIONS

Despite the significant contribution made by this study to STEM education in Kazakhstan, there exist a number of shortcomings and limitations. They affect the scope of generalizations, validity, and reliability of findings.

1. Geographical narrowness. Due to the limited geographical distribution of the sample (three cities), the findings obtained cannot fully cover experiences and challenges of schools in rural areas, smaller cities, or in other regions of Kazakhstan, which may have different resources, teacher qualification, students, etc. Future research needs to address this limitation.

2. Short intervention period. As this study took four to five weeks, it was too short to examine long-term effects on knowledge retention, skill development, attitudes towards chemistry, etc. Teachers noted that their students needed additional time to adjust. For this reason, longitudinal designs seem preferable for capturing the full range of STEM outcomes.

3. Design. As compared to randomized controlled experiments, this study used a quasi-experiment that did not provide as much certainty regarding the causes. Despite pre-test results were used to ensure the equivalence of the groups and ANCOVA helped to control for pre-test differences, the latter may still have occurred, e.g., differences in the motivational level or preexisting exposure to interdisciplinary studies.

4. Ceiling effect. High baseline knowledge of State and Specialized Schools students resulted in a ceiling effect limiting the detectable short-term improvement in the experiment. This affects the conclusions that can be drawn about the effectiveness for high-achievers.

5. Limitation in the measurement range. As the pre- and post-tests only assessed chemistry content knowledge and not other aspects of STEM-related outcomes, some outcomes may not have been detected, thus leading to underestimating the true impact of the STEM unit plan. Future research needs to use a broader measurement scale.

6. Purtasive sample of teachers. As the purposively selected teachers already had experience with STEM integration, it appears difficult to generalize the findings to all

of Kazakhstan's teachers. The former's experiences may differ significantly from those of teachers with less experience.

7. Online modality. An online interview may limit the depth of the collected qualitative data compared to in-person ones because of the loss of certain communication elements (non-verbal cues).

8. Subject-specificity. Chemistry served as the only discipline in which STEM was introduced. Although it provided a good platform for interdisciplinary studies, other science disciplines (biological, physical) or even mathematics need to be considered**.**

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APPENDICES

Semi-Structured Interview Protocol ***Appendix 1***

1) Have you ever implemented STEM education tools—such as 3D modeling, augmented reality (AR), virtual reality (VR), robotics, software programs, or artificial intelligence (AI) applications—in the teaching and learning process? / Оқыту процесікезінде STEM арқылы білім беру үшінқолданылатын құралдарды қолданып көргенсізбе? (3D модельдеу, кеңейтілген шындық (AR), виртуалды шындық (VR), робототехника, бағдарламалық қамтамасыз ету немесе жасандыинтеллект (AI) қолданбалары сияқты құралдар)

2) If so, to what extent has the use of these toolscontributed to increased student engagement, understanding, and overall quality of learningoutcomes? / Егер қолданған болсаңыз, бұл құралдароқушылардың сабақты түсінуіне, белсенділігінежәне жалпы оқу сапасының артуына қаншалықтыәсер етті?

3) What concrete 21st-century skills (e.g., criticalthinking, problem-solving, creativity, collaboration) can be effectively developed through STEM-basedlearning activities and methods? /STEM негізіндегіоқу әрекеттері мен әдістері арқылы 21 ғасырдыңмаңызды дағдыларын (сыни және креативтіойлау, коллаборация мен коммуникация, мәселелерді шеше алу)тиімді дамытуға болады

4) What types of learning strategies or classroom activities can best facilitate the integration of STEM tools to enhance student learning experiences and outcomes?/ Оқыту стратегияларының немесесыныптағы іс-шаралардың қандай түрлеріоқушылардың оқу тәжірибесі мен нәтижелерінжақсарту үшін STEM құралдарын енгізудіжеңілдетуі мүмкін?

5) What challenges or drawbacks have you experiencedin integrating STEM-based tools, methods into thelearning process? / STEM негізіндегі

құралдарды, әдістерді оқыту процессі кезіндеқолданғаныңызда қандай қиындықтармен, кемшліктермен бетпе-бет келдіңіз?

6) In your opinion, should all Kazakhstani schools implement STEM-based teaching methods? What factors (such as resources, teacher preparation, and support) might influence their successful acceptance?/ Сіздің ойыңызша, Қазақстанныңбарлық мектептері STEM негізіндегі оқытуәдістерін енгізуі керек пе? Олардың сәтті енгізілуіне қандай факторлар әсер етуі мүмкін (ресурстар, мұғалімдерді даярлау және қолдау)? / На ваш взгляд, должны ли все казахстанскиешколы внедрять методы обучения, основанныена STEM?

Pre-Test and Post-Test instruments ***Appendix 2***

Pre-Test: Private School

1. What percentage of the Earth's atmosphere is nitrogen gas (N_2)?

[Bloom: Remember]

a) 21%

b) 50%

c) 78%

d) 1%

2. What is the chemical formula of ammonia?

[Bloom: Remember]

a) NO_2

b) NH_3

c) N_2O

d) HNO_3

3. What is the oxidation state of nitrogen in HNO_3?

[Bloom: Remember]

a) -3

b) 0

c) +3

d) +5

4. Which process is used industrially to produce ammonia?

[Bloom: Remember]

a) Contact Process

b) Solvay Process

c) Haber-Bosch Process

d) Ostwald Process

5. What is the oxidation state of sulfur in H_2SO_4?

[Bloom: Remember]

a) -2

b) +4

c) 0

d) +6

6. Why is N_2 chemically unreactive at room temperature?

[Bloom: Understand]

a) It is a noble gas

b) It has a very strong triple bond

c) It has low molar mass

d) It dissolves in water

7. What type of sulfur allotrope is stable at room temperature?

[Bloom: Understand]

a) Monoclinic sulfur

b) Plastic sulfur

c) Rhombic sulfur (S_8)

d) Amorphous sulfur

8. What causes acid rain? Which gas is mainly responsible?

[Bloom: Understand]

a) CO_2 only

b) SO_2 reacting with water to form H_2SO_3

c) NH_3

d) N_2

9. In the Contact Process, what catalyst is used to convert SO_2 to SO_3?

[Bloom: Understand]

a) Iron (Fe)

b) Platinum (Pt)

c) Vanadium pentoxide (V_2O_5)

d) Nickel (Ni)

10. What is produced when ammonia reacts with oxygen in the Ostwald Process?

[Bloom: Understand]

a) N_2 and H_2O

b) NO and H_2O

c) NO_2 only

d) HNO_2

11. In the Haber-Bosch process: $N_2 + 3H_2 \rightarrow 2NH_3$. If 28g of N_2 reacts, how many grams of NH_3 are theoretically produced?

[Bloom: Apply]

a) 17g

b) 28g

c) 34g

d) 51g

12. Calculate the molar mass of H_2SO_4.

[Bloom: Apply]

a) 80 g/mol

b) 96 g/mol

c) 98 g/mol

d) 100 g/mol

13. Contact Process: $2SO_2 + O_2 \rightarrow 2SO_3$. If 32g of SO_2 reacts, how many grams of SO_3 are produced?

[Bloom: Apply]

a) 32g

b) 40g

c) 80g

d) 64g

14. What conditions are used in the Haber-Bosch process?

[Bloom: Apply]

a) 1000°C, low pressure, Pt catalyst

b) 450°C, 200 atm, Fe catalyst

c) 200°C, 1 atm, V_2O_5 catalyst

d) 800°C, 100 atm, Ni catalyst

15. A factory emits 64g of SO_2/hour. How many moles of SO_2 is this?

[Bloom: Apply]

a) 0.5 mol

b) 1 mol

c) 2 mol

d) 4 mol

PART B: MATCHING — Nitrogen & Sulfur (Pre-Test)

[Bloom: Understand]

Match each term in Column A with the correct definition in Column B.

COLUMN A — Terms	Answer	COLUMN B — Definitions
1. Haber-Bosch Process	-	A) Industrial synthesis of NH_3 from N_2 and H_2 at 450°C, 200 atm, Fe catalyst
2. Contact Process	-	B) Industrial production of H_2SO_4 via $SO_2 \rightarrow SO_3$ using V_2O_5 at 450°C
3. Acid rain	-	C) Precipitation with pH below 5.6 caused by SO_2 and NO_x in atmosphere
4. Rhombic sulfur	-	D) Most stable allotrope of sulfur at room temperature; S_8 ring structure
5. Oxidation state-	-	E) Hypothetical charge an atom would have if all bonds were fully ionic

PART C: OPEN QUESTIONS (Pre-Test)

16. Explain why nitrogen gas (N_2) does not react easily with other chemicals at room temperature. In your answer, refer to the type and strength of the bonding in N_2. (3 marks)

[Bloom: Understand]

17. Describe the Contact Process for the industrial production of sulfuric acid. Include the key steps, chemical equations, and the conditions (temperature, catalyst) used in the main step. (3 marks)

[Bloom: Understand]

18. A student says: 'Nitrogen fertilisers are always beneficial for the environment.' Do you agree or disagree? Give two reasons to support your answer. (3 marks)

[Bloom: Apply]

PART A: MULTIPLE CHOICE QUESTIONS (15 marks — 1 mark each)

1. Which of the following correctly ranks nitrogen's oxidation states from most negative to most positive?
[Bloom: Understand]

a) -3, 0, +2, +4, +5
b) +5, +4, +2, 0, -3
c) 0, -3, +2, +4, +5
d) -3, +2, 0, +4, +5

2. In the reaction $Cu + 4HNO_3(conc) \rightarrow Cu(NO_3)_2 + 2NO_2 + 2H_2O$, what is the oxidation state of N in NO_2?
[Bloom: Apply]

a) +2
b) +3
c) +4
d) +5

3. Why does the Haber-Bosch process use 450°C rather than a higher temperature, even though higher temperatures speed up reactions?
[Bloom: Analyze]

a) Iron catalyst melts above 450°C
b) Higher temperatures shift equilibrium left, reducing NH_3 yield
c) H_2 becomes unreactive above 450°C
d) N_2 decomposes above 450°C

4. Which statement about sulfur allotropes is correct?
[Bloom: Understand]

a) Monoclinic sulfur is stable at room temperature
b) Rhombic sulfur converts to monoclinic above 96°C
c) Both allotropes have the same melting point
d) Plastic sulfur is the most stable form

5. In the Contact Process, why is SO_3 absorbed into concentrated H_2SO_4 rather than water?
[Bloom: Understand]

a) Water is too expensive
b) Adding SO_3 to water directly creates dangerous uncontrollable acid mist
c) SO_3 does not react with water
d) Concentrated H_2SO_4 is cheaper

6. Nitrogen fixation converts N_2 into usable nitrogen compounds. Which organism can fix nitrogen naturally?

[Bloom: Understand]

a) Oak trees

b) Wheat plants

c) Rhizobium bacteria in root nodules

d) Algae only

7. Calculate the percentage yield of NH_3 if 100g N_2 produces 85g NH_3. (Theoretical yield = 121.4g)

[Bloom: Apply]

a) 57.7%

b) 70.0%

c) 85.0%

d) 121.4%

8. How many grams of $Ca(OH)_2$ are needed to neutralise 64g of SO_2? ($SO_2 + Ca(OH)_2 \rightarrow CaSO_3 + H_2O$)

[Bloom: Apply]

a) 37g

b) 56g

c) 74g

d) 148g

9. What is the atom economy of the Haber-Bosch process: $N_2 + 3H_2 \rightarrow 2NH_3$?

[Bloom: Apply]

a) 50%

b) 75%

c) 85%

d) 100%

10. $SO_2 + H_2O \rightarrow H_2SO_3$. This reaction is responsible for acid rain. What is the pH of a solution with $[H^+] = 0.01$ mol/L?

[Bloom: Apply]

a) pH = 1

b) pH = 2

c) pH = 3

d) pH = 7

11. Which industrial process uses the product of the Haber-Bosch process as a starting material to make nitric acid?

[Bloom: Analyze]

a) Contact Process

b) Solvay Process

c) Ostwald Process

d) Frasch Process

12. A sample of 2.5 mol/L NH_4NO_3 solution contains how many grams of NH_4NO_3 in 400mL?

[Bloom: Apply]

a) 60g

b) 80g

c) 100g

d) 120g

13. What environmental problem is directly linked to excess nitrogen fertiliser runoff into rivers?

[Bloom: Analyze]

a) Acid rain

b) Eutrophication leading to oxygen depletion

c) Ozone depletion

d) Global warming

14. In the reaction $2SO_2 + O_2 \rightleftharpoons 2SO_3$, increasing pressure shifts equilibrium to the right. Why?

[Bloom: Analyze]

a) Fewer moles of gas on the right side

b) More moles of gas on the right side

c) Temperature increases

d) Catalyst becomes more active

15. Which combination of conditions gives the highest equilibrium yield of NH_3 in the Haber-Bosch process?

[Bloom: Analyze]

a) High temperature, low pressure

b) Low temperature, high pressure

c) High temperature, high pressure

d) Low temperature, low pressure

PART B: MATCHING — Nitrogen & Sulfur (Post-Test)

[Bloom: Analyze]

Match each term in Column A with the correct definition in Column B.

COLUMN A — Terms	Answer	COLUMN B — Definitions
1. Ostwald Process	-	A) Industrial conversion of NH_3 to HNO_3: $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$; then $NO \rightarrow NO_2 \rightarrow HNO_3$

2. Le Chatelier's Principle	-	B) A system at equilibrium will shift to oppose any change in conditions (temperature, pressure, concentration)
3. Nitrogen fixation	-	C) Conversion of atmospheric N_2 into nitrogen compounds usable by living organisms — occurs industrially (Haber) or biologically (bacteria)
4. Eutrophication	-	D) Excessive nutrient enrichment of water bodies (often from nitrogen fertiliser runoff) leading to algal bloom and oxygen depletion
5. Atom economy	-	E) Percentage of atoms in reactants that end up in the desired product: (mass of desired product / total mass of products) × 100%

PART C: OPEN QUESTIONS (Post-Test)

16. Explain how the Haber-Bosch process uses the principles of chemical equilibrium to maximise ammonia yield. In your answer, discuss the effect of temperature, pressure, and catalyst on both the rate and yield of the reaction. (3 marks)
[Bloom: Analyze]

17. A power station burns coal containing 2% sulfur. Explain the complete pathway from sulfur in coal to acid rain formation, including all relevant chemical equations. Suggest one engineering solution to reduce SO_2 emissions from the power station. (3 marks)
[Bloom: Analyze]

18. Evaluate the statement: 'The Haber-Bosch process has been both the most beneficial and most harmful chemical process in human history.' Discuss both sides of this argument using specific chemical and environmental evidence. (3 marks) *[Bloom: Evaluate]*

Expert Evaluation Form: Pre-Test

Pre-test бағалау формасы

"11-сынып оқушыларының «Химия» пәні бойынша білімін анықтауға арналған пре-тесттің мазмұндық валидтілігін
бағалау"

*Обязательный вопрос

Пре-тест сұрақтары қойылған мақсатқа сәйкес келе ме? *

- ◯ 1 - сәйкес келмейді
- ◯ 2- жартылай сәйкес
- ◯ 3- толық сәйкес

Пре-тест химия пәнінің негізгі аспектілерін қамтиды ма? *

- ◯ 1 - жеткіліксіз
- ◯ 2- жартылай жеткілікті
- ◯ 3- толық жеткілікті

Пре-тест сұрақтары нақты, түсінікті және анық құрастырылған ба? *

- ◯ 1 - түсініксіз
- ◯ 2- жартылай түсінікті
- ◯ 3 - толық түсінікті

Пре-тест сұрақтарының жауаптары химия пәнінің маңызды түсініктерін дұрыс бағалауға мүмкіндік бере ме? *

- ◯ 1 - жарамсыз
- ◯ 2 - жартылай жарамды
- ◯ 3- толық жарамды

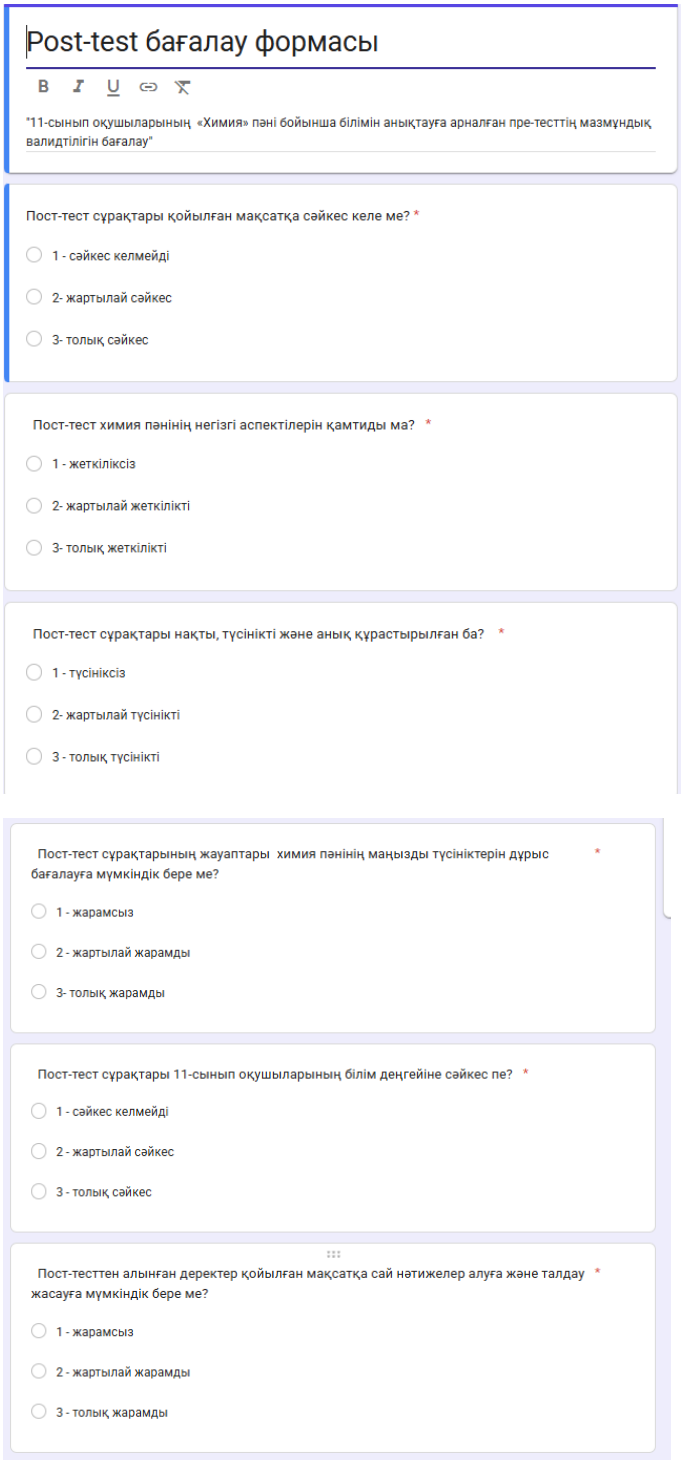
Пре-тест сұрақтары 11-сынып оқушыларының білім деңгейіне сәйкес пе? *

- ◯ 1 - сәйкес келмейді
- ◯ 2 - жартылай сәйкес
- ◯ 3 - толық сәйкес

Пре-тесттен алынған деректер қойылған мақсатқа сай нәтижелер алуға және талдау жасауға мүмкіндік бере ме? *

- ◯ 1 - жарамсыз
- ◯ 2 - жартылай жарамды
- ◯ 3 - толық жарамды

Expert Evaluation Form: Post-Test



Expert Evaluation Form: Interview Protocol

Раздел 1 из 2

Content validity

Құрметті эксперт!
Сіздің алдыңызда «Creating the Integrative STEM Lesson Unit Plan for 11th Grade Students» атты зерттеу аясында дайындалған сұхбат сұрақтарының мазмұндық валидтілігін бағалау үшін критерийлер көрсетілген.

Сізден әр сұрақты төмендегі критерийлер бойынша 1-ден 4-ке дейінгі баллмен бағалауыңызды сұраймыз.
Бағалау нәтижелері зерттеу құралының сапасын арттыруға, сұрақтардың анықтығы мен мазмұндық сәйкестігін қамтамасыз етуге көмектеседі.

Сіздің уақытыңыз бен кәсіби пікіріңіз зерттеу үшін өте маңызды.
Рақмет!

Dear Expert,
You are invited to evaluate the content validity of the interview questions developed for the research titled «Creating the Integrative STEM Lesson Unit Plan for 11th Grade Students».

Please rate each question according to the criteria listed below using a 4-point scale.
Your feedback will help improve the quality of the instrument and ensure the clarity, relevance, and appropriateness of each question.

Your time and professional opinion are highly appreciated.
Thank you!

2. Жұмыс орны/Institution *

Краткий ответ

3. Лауазымы/Position *

Краткий ответ

4. Еңбек өтіліңіз *

Краткий ответ

После раздела 1 Перейти к разделу 2 (Content validity)

Раздел 2 из 2

Content validity

Диссертация тақырыбы: Creating the Integrative STEM Lesson Unit Plan for 11th Grade Students

Have you ever implemented STEM education tools—such as 3D modeling, augmented reality (AR), virtual reality (VR), robotics, software programs, or artificial intelligence (AI) applications—in the teaching and learning process? / Оқыту процесі кезінде STEM арқылы білім беру үшін қолданылатын құралдарды қолданып көргенсіз бе? (3D модельдеу, кеңейтілген шындық (AR), виртуалды шындық (VR), робототехника, бағдарламалық қамтамасыз ету немесе жасанды интеллект (AI) қолданбалары сияқты құралдар) *

	1 – Not relevant / ...	2 – Partly relevant ...	3 – Mostly relevan...	4 – Fully relevant /...
Clarity (айқындыл...	○	○	○	○
Relevance (зертте...	○	○	○	○
Content coverage (...	○	○	○	○
Comprehensibility ...	○	○	○	○
Ethics (этикалық ...	○	○	○	○
Usefulness (талда...	○	○	○	○

If so, to what extent has the use of these tools contributed to increased student engagement, understanding, and overall quality of learning outcomes? / Егер қолданған болсаңыз, бұл құралдар оқушылардың сабақты түсінуіне, белсенділігіне және жалпы оқу сапасының артуына қаншалықты әсер етті? *

	1 – Not relevant / ...	2 – Partly relevant ...	3 – Mostly relevan...	4 – Fully relevant /...
Clarity (айқындыл...	○	○	○	○
Relevance (зертте...	○	○	○	○
Content coverage (...	○	○	○	○
Comprehensibility ...	○	○	○	○
Ethics (этикалық ...	○	○	○	○
Usefulness (талда...	○	○	○	○

What concrete 21st-century skills (e.g., critical thinking, problem-solving, creativity, collaboration) can be effectively developed through STEM-based learning activities and methods? /STEM негізіндегі оқу әрекеттері мен әдістері арқылы 21 ғасырдың маңызды дағдыларын (сыни және креативті ойлау, коллаборация мен коммуникация, мәселелерді шеше алу)тиімді дамытуға болады? *

	1 – Not relevant / ...	2 – Partly relevant ...	3 – Mostly relevan...	4 – Fully relevant /...
Clarity (айқындыл...	○	○	○	○
Relevance (зертте...	○	○	○	○
Content coverage (...	○	○	○	○
Comprehensibility ...	○	○	○	○
Ethics (этикалық ...	○	○	○	○
Usefulness (талда...	○	○	○	○

What types of learning strategies or classroom activities can best facilitate the integration of STEM tools to enhance student learning experiences and outcomes?/ Оқыту стратегияларының немесе сыныптағы іс-шаралардың қандай түрлері оқушылардың оқу тәжірибесі мен нәтижелерін жақсарту үшін STEM құралдарын енгізуді жеңілдетуі мүмкін? *

	1 – Not relevant / ...	2 – Partly relevant ...	3 – Mostly relevan...	4 – Fully relevant /...
Clarity (айқындыл...	○	○	○	○
Relevance (зертте...	○	○	○	○
Content coverage (...	○	○	○	○
Comprehensibility ...	○	○	○	○
Ethics (этикалық ...	○	○	○	○
Usefulness (талда...	○	○	○	○

What challenges or drawbacks have you experienced in integrating STEM-based tools, methods into the learning process? / STEM негізіндегі құралдарды, әдістерді оқыту процессі кезінде қолданғаныңызда қандай қиындықтармен, кемшіліктермен бетпе-бет келдіңіз? *

	1 – Not relevant / ...	2 – Partly relevant ...	3 – Mostly relevan...	4 – Fully relevant /...
Clarity (айқындыл...	○	○	○	○
Relevance (зертте...	○	○	○	○
Content coverage (...	○	○	○	○
Comprehensibility ...	○	○	○	○
Ethics (этикалық ...	○	○	○	○
Usefulness (талда...	○	○	○	○

In your opinion, should all Kazakhstani schools implement STEM-based teaching methods? What factors (such as resources, teacher preparation, and support) might influence their successful acceptance?/ Сіздің ойыңызша, Қазақстанның барлық мектептері STEM негізіндегі оқыту әдістерін енгізуі керек пе? Олардың сәтті енгізілуіне қандай факторлар әсер етуі мүмкін (ресурстар, мұғалімдерді даярлау және қолдау)? *

	1 – Not relevant / ...	2 – Partly relevant ...	3 – Mostly relevan...	4 – Fully relevant /...
Clarity (айқындыл...	○	○	○	○
Relevance (зертте...	○	○	○	○
Content coverage (...	○	○	○	○
Comprehensibility ...	○	○	○	○
Ethics (этикалық ...	○	○	○	○
Usefulness (талда...	○	○	○	○

Interview validation

	Q1	Q2	Q3	Q4	Q5	Q6
Exp 1	4.00	4.00	4.00	4.00	4.00	4.00
Exp 2	3.00	4.00	3.00	3.00	4.0	4.00
Exp 3	4.00	4.00	4.00	4.00	4.0	4.00
Exp 4	3.00	3.00	3.00	3.00	3.0	3.00
Exp 5	4.00	4.00	4.00	4.00	4.0	4.00

Kendall's W Test Ranks

	Mean Rank
Question_1	3,20
Question_2	4,40
Question_3	3,20
Question_4	3,20
Question_5	4,40
Question_6	4,40

Test Statistics

N	5
Kendall's W[a]	,820
Chi-Square	20,500
df	5
Asymp. Sig.	,0001

a. Kendall's Coefficient of Concordance

Pre/Post-test validation

	Q1	Q2	Q3	Q4	Q5	Q6
Exp 1	4.00	4.00	5.00	4.00	2.00	4.00
Exp 2	3.00	2.00	4.00	3.00	2.00	4.00
Exp 3	4.00	3.00	5.00	3.00	3.00	4.00
Exp 4	4.00	4.00	5.00	4.00	2.00	5.00
Exp 5	3.00	3.00	5.00	4.00	2.00	5.00

Kendall's W Test Ranks

	Mean Rank
Question_1	3,30
Question_2	3,30
Question_3	3,30
Question_4	3,30
Question_5	3,30
Question_6	4,50

Test Statistics

N	5
Kendall's W[a]	,790
Chi-Square	19,750
df	5
Asymp. Sig.	,0001

a.Kendall's Coefficient of Concordance

Table 1. Integrative STEM Unit Plan: Topics, Learning Objectives, Hours, STEM Components, Teaching Methods, and Literature Sources

No.	**Topic**	**Learning Objective / Outcome**	**Hours**	**STEM Component**	**Teaching Method**	**Literature Source**
UNIT 1: Elements of Groups IV and V | (Nitrogen + Sulfur) + (Carbon + Silicon) | Implemented						
Private School | Topics: Nitrogen (N) and Sulfur (S)						
1	Nitrogen (N): Properties and Oxidation States	Students identify the position of nitrogen in Group V, describe its oxidation states (-3 to +5), and explain why N2 is chemically unreactive.	1	**SCIENCE**	5E Instructional Model (Engage-Explore-Explain): Students observe PhET Molecule Polarity simulation to explore N≡N triple bond, then watch virtual Cu + HNO3 reaction.	Bybee et al. (2006). The BSCS 5E instructional model. BSCS.
2	Nitrogen (N): Haber-	Students explain the industrial	1	**SCIENCE +**	Technology-integrated instruction:	Yesgat et al. (2023). Effects of

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
	Bosch Process	synthesis of ammonia using the Haber-Bosch process, state reaction conditions, and evaluate the environmental impact of nitrogen fertilisers.		**TECHNOLOGY**	students use ChemSketch to draw NH3 and HNO3 molecules, then create a digital Google Slides poster connecting nitrogen chemistry to real-world agricultural applications.	technology-integrated chemistry instruction. Journal of Education and Learning, 17(4), 696-709.
3	Nitrogen (N): Engineering Application	Students design a nitrogen fertiliser delivery system for a Kazakhstani farm that maximises crop uptake and minimises	1	**ENGINEERING**	Engineering Design-Based STEM Integration: students follow a structured design process (define-research-sketch-present) to apply	Guzey et al. (2016). Building up STEM: An analysis of teacher-developed engineering design-based

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
		environmental runoff.			nitrogen chemistry to a real agricultural engineering challenge.	STEM integration. J-PEER, 6(1), 2.
4	Nitrogen (N): Stoichiometric Calculations	Students calculate molar mass, percentage yield of the Haber-Bosch process, and concentration of nitrogen fertiliser solutions.	1	**MATHEMATICS**	Integrated STEM mathematics application: quantitative calculations are directly linked to the engineering design from the previous lesson, demonstrating authentic interdisciplinary connections.	Kelley & Knowles (2016). A conceptual framework for integrated STEM education. IJ STEM Ed, 3(11).

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
5	Sulfur (S): Allotropes and Oxidation States	Students describe rhombic and monoclinic sulfur allotropes, identify oxidation states of sulfur (-2 to +6), and explain acid rain formation from SO2 emissions.	1	**SCIENCE**	5E Inquiry-Based Learning: students use PhET Acid-Base simulation to observe SO2 reacting with water, record pH changes, and connect to acid rain chemistry before teacher explanation.	Kennedy & Odell (2014). Engaging students in STEM education. Science Education International, 25(3), 246-258.
6	Sulfur (S): Contact Process	Students write equations for all steps of the Contact Process and explain the role of the V2O5 catalyst and industrial	1	**SCIENCE + TECHNOLOGY**	Geospatial technology integration: students use Google Earth to locate real industrial SO2-emitting facilities near Almaty and	Osadchyi et al. (2021). Using augmented reality technologies for STEM education.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
		conditions used.			annotate a digital map with relevant chemical equations.	Journal of Physics: Conference Series, 1840(1), 012027.
7	Sulfur (S): Engineering — SO2 Scrubber	Students design a wet scrubber system using Ca(OH)2 to neutralise SO2 emissions from a factory chimney, applying acid-base chemistry to an environmental engineering problem.	1	**ENGINEERING**	Problem-Based Engineering Design: students apply the STEM problem-solving approach to design an industrial pollution control system, connecting chemistry knowledge to real environmental challenges in Kazakhstan.	Alkair et al. (2023). A STEM model for engaging students in environmental sustainability programs. Applied Environmental Education & Communication,

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
						22(1), 13-26.
8	Sulfur (S): Stoichiometric Calculations	Students calculate percentage composition of H2SO4, Contact Process stoichiometry, and the mass of Ca(OH)2 needed to neutralise industrial SO2 emissions.	1	**MATHEMATICS**	Mathematics in authentic STEM contexts: calculations are directly connected to the scrubber engineering design, demonstrating how mathematics quantifies and validates engineering solutions.	Stohlmann et al. (2012). Considerations for teaching integrated STEM education. J-PEER, 2(1), Article 4.
State School | Topics: Carbon (C) and Silicon (Si)						
9	Carbon (C): Allotropes and	Students explain sp3 hybridisation in diamond and	1	**SCIENCE**	5E Constructivist Learning: students build	Vygotsky (1978). Mind in society.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
	Hybridisation	sp2 in graphite, compare their physical properties, and relate structure to electrical conductivity.			physical 3D molecular models of diamond and graphite to discover the relationship between bonding structure and physical properties before teacher explanation.	Harvard University Press; Piaget (1970). Piaget's theory. In Carmichael's manual of child psychology.
10	Carbon (C): Graphene and Fullerene	Students describe the structure and properties of graphene and fullerene (C60) and evaluate their potential technological applications.	1	**SCIENCE + TECHNOLOGY**	3D Digital Modelling Integration: students use Tinkercad (free, browser-based) to create 3D models of diamond, graphite, and fullerene,	Lavicza et al. (2022). Developing and evaluating educational innovations for STEAM education.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
					annotating each with hybridisation type, conductivity, hardness, and real-world application.	Sustainability, 14(12), 7237.
11	Carbon (C): Engineering — Water Filtration	Students design and test a simple activated carbon water filter, explain the adsorption mechanism, and evaluate filter effectiveness using before/after colour comparison.	1	**ENGINEERING**	Hands-on Engineering Design Process: students follow a design-build-test-evaluate cycle using activated carbon, connecting sp2 carbon structure (graphite/graphene) to its industrial application in water purification.	Moore et al. (2014). Implementation and integration of engineering in K-12 STEM education. Purdue University Press.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
12	Carbon (C): Empirical Formula and CO2 Calculations	Students calculate empirical and molecular formulae from percentage composition data and calculate CO2 volumes from combustion reactions.	1	**MATHEMATICS**	Real-world data mathematics: calculations are contextualised using Kazakhstan's annual CO2 emissions data, connecting stoichiometry to global environmental issues and developing quantitative environmental literacy.	Gao et al. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. IJ STEM Ed, 7(24).
13	Silicon (Si): Structure and Semiconductor Properties	Students explain silicon's giant covalent structure, describe band theory and the concept of band	1	**SCIENCE**	Digital simulation-based inquiry: students use PhET Band Structure simulation to explore and	Kefalis & Drigas (2019). Web based and online applications in STEM education.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
		gap, and distinguish between conductors, semiconductors, and insulators.			compare the electronic band structures of copper (conductor), silicon (semiconductor), and glass (insulator) before teacher explanation.	International Journal of Engineering Pedagogy, 9(4), 76-85.
14	Silicon (Si): Solar Cell Technology	Students explain the photovoltaic effect, describe p-type and n-type doping, and trace silicon's journey from sand (SiO_2) to a functioning solar panel.	1	**SCIENCE + TECHNOLOGY**	Infographic technology task: students create a 5-step digital infographic in Canva or Google Slides tracing the chemical journey from SiO_2 to electrical energy,	Istrate et al. (2019). The use of technology in STEM education. Journal of Pedagogy, 1, 73-91.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
					including relevant chemical equations at each step.	
15	Silicon (Si): Engineering — Solar Water Pump	Students design a solar-powered water pump system for a remote Kazakhstani village, specifying solar panel array, battery storage, pump type, and water pipe layout.	1	**ENGINEERING**	Contextualised engineering design: students apply photovoltaic chemistry and energy calculations to design a renewable energy system addressing a real infrastructure need in rural Kazakhstan, aligned with Kazakhstan's 2030 renewable energy targets.	Hsiao & Su (2021). A study on the impact of STEAM education for sustainable development. Sustainability, 13(7), 3772.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
16	Silicon (Si): Energy and Mole Calculations	Students calculate moles of SiO2 in crustal rock, energy output of solar panels in kWh, and the number of panels required to power a school building.	1	**MATHEMATICS**	Applied mathematics in renewable energy contexts: calculations connect silicon chemistry directly to solar energy engineering, demonstrating the quantitative foundation of sustainable technology design.	Kelley & Knowles (2016). A conceptual framework for integrated STEM education. IJ STEM Ed, 3(11).
UNIT 2: New Materials and Solutions |Specialized School | Implemented						
Specialized School | Topics: New Materials + Acid/Base Solutions						
17	Polymers: Addition and Condensa	Students distinguish between addition and condensation	1	**SCIENCE**	5E Inquiry with hands-on synthesis: students synthesise a	Rahmawati et al. (2019). Developing critical

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
	tion Polymerisation	polymerisation, write equations for polyethylene and nylon-6,6 synthesis, and explain why biodegradable plastics decompose while conventional polyethylene does not.			simple bioplastic from cornstarch, water, vinegar, and glycerin, observing the polymerisation process and comparing properties to conventional plastic before formal explanation.	and creative thinking skills through STEAM integration in chemistry. Journal of Physics: Conference Series, 1156(1), 012033.
18	Polymers: Nanomaterials and Smart Materials	Students describe the properties of nanomaterials (particles below 100 nm) and smart materials (shape-memory alloys,	1	**SCIENCE + TECHNOLOGY**	3D design technology integration: students use Tinkercad to design a 3D-printable biodegradable product, annotating their	Osadchyi et al. (2021). Using augmented reality technologies for STEM education.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
		piezoelectrics), and evaluate their real-world technological applications.			design with polymer type, polymerisation method, required properties, and comparison with traditional materials.	Journal of Physics: Conference Series, 1840(1), 012027.
19	Polymers: Engineering — Anti-Corrosion Coating	Students design a 3-layer anti-corrosion polymer coating system for steel infrastructure in Kazakhstan, specifying the polymer compound for each layer, application method, and calculating the total cost.	1	**ENGINEERING**	Industry-contextualised engineering design: students apply polymer chemistry to address Kazakhstan's pipeline corrosion challenge, following a professional engineering specification process that	Guzey et al. (2016). Building up STEM: An analysis of teacher-developed engineering design-based STEM integration. J-PEER, 6(1), 2.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
					integrates chemistry, material science, and cost analysis.	
20	Polymers: Molar Mass and Yield Calculations	Students calculate the molar mass of polymers from degree of polymerisation, calculate percentage yield of bioplastic synthesis, and determine the total cost of anti-corrosion coating for a specified infrastructure area.	1	**MATHEMATICS**	Authentic cost-benefit mathematics: calculations are directly embedded in the engineering coating design, demonstrating how polymer mathematics enables evidence-based engineering decision-making.	Stohlmann et al. (2012). Considerations for teaching integrated STEM education. J-PEER, 2(1), Article 4.
21	Acid-Base	Students compare	1	**SCIENCE**	5E Inquiry with hands-on	Kennedy & Odell

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
	Solutions: Theories and pH Scale	Arrhenius, Bronsted-Lowry, and Lewis acid-base theories, calculate pH for strong and weak acids, and explain the role of Ka in measuring acid strength.			titration: students test household substances with universal indicator, then conduct a titration of HCl with NaOH using phenolphthalein, plotting a 5-point titration curve before formal theoretical explanation.	(2014). Engaging students in STEM education. Science Education International, 25(3), 246-258.
22	Acid-Base Solutions: Buffer Systems and Henderson-	Students explain what a buffer solution is, apply the Henderson-Hasselbalch equation, and describe how	1	**SCIENCE + TECHNOLOGY**	Digital simulation comparison: students use PhET Acid-Base Solutions to model and compare	Kefalis & Drigas (2019). Web based and online applications in STEM education.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
	Hasselbalch	the blood bicarbonate buffer system maintains pH at 7.35-7.45.			titration curves for strong acid/strong base and weak acid/strong base combinations, recording data in Google Sheets and creating dual-curve graphs.	International Journal of Engineering Pedagogy, 9(4), 76-85.
23	Acid-Base Solutions: Engineering — Water Treatment	Students design a chemical water treatment system to neutralise acid mine drainage (pH 4.5) to WHO drinking water standard (pH 6.5-7.5), specifying neutralising agent, treatment steps,	1	**ENGINEERING**	Environmental engineering design challenge: students apply acid-base chemistry to address Kazakhstan's acid mine drainage problem (Karaganda/Zhezkazgan	Alkair et al. (2023). A STEM model for engaging students in environmental sustainability programs. Applied Environmental

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
		and calculating daily cost.			regions), integrating stoichiometry, cost analysis, and environmental chemistry in an authentic design task.	Education & Communication, 22(1), 13-26.
24	Acid-Base Solutions: pH and Buffer Calculations	Students calculate pH for strong acids, weak acids (using ICE table), and buffer solutions; solve titration stoichiometry problems; and apply Henderson-Hasselbalch to calculate the	1	**MATHEMATICS**	Logarithmic mathematics in authentic biological and engineering contexts: calculations connect acid-base theory to both the water treatment engineering design and human blood chemistry, demonstrating	Gao et al. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. IJ STEM Ed, 7(24).

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
		blood buffer ratio.			the universal applicability of pH mathematics.	
UNIT 3: Organic Synthesis and Synthetic Polymers | Further Study (Not Implemented — Proposed for Future Research)						
Proposed for 11th Grade Chemistry | Topics: §30–§36 Organic Chemistry and Polymer Science						
25	§30. Fundamental Concepts of High Molecular Weight Compounds	Students define polymer, monomer, repeat unit, and degree of polymerisation; distinguish between natural and synthetic polymers; and explain the relationship between polymer chain length and	1	**SCIENCE**	Constructivist concept mapping: students create a concept map connecting key polymer terminology before formal instruction, activating prior knowledge from Unit 1 (New Materials) and building a	Vygotsky (1978). Mind in society. Harvard University Press; Bybee et al. (2006). The BSCS 5E instructional model. BSCS.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
		physical properties.			cognitive framework for the unit.	
26	§31. Polymerisation Reactions	Students write equations for addition polymerisation reactions (ethylene → polyethylene; propylene → polypropylene; vinyl chloride → PVC), identify the conditions required, and explain the mechanism using the concept of pi bond opening.	1	**SCIENCE + TECHNOLOGY**	Digital molecular modelling: students use ChemSketch to draw monomer and polymer structures for polyethylene, polypropylene, and PVC, annotating bond types and comparing chain structures. This visual approach supports understanding of the polymerisation mechanism.	Aroch et al. (2024). Modes of technology integration in chemistry teaching. Chemistry Education Research and Practice, 25(3), 843-861.

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
27	§32. Condensation Reactions: Polyamides and Polyesters	Students write equations for condensation polymerisation reactions producing nylon-6,6 (from adipic acid and hexamethylene diamine) and polyester (Terylene), identify the small molecule released at each bond, and compare properties with addition polymers.	1	**SCIENCE**	Comparative inquiry: students physically model nylon synthesis using the 'nylon rope trick' demonstration (if available) or observe a video, then compare the mechanism step-by-step with addition polymerisation, developing deeper understanding through contrast.	Ceylan & Ozdilek (2015). Improving a sample lesson plan for secondary science courses within STEM education. Procedia-Social and Behavioral Sciences, 177, 223-228.
28	§33. Applications of	Students evaluate the environmental	1	**ENGINEERING + SCIENCE**	Sustainability-focused STEM integration:	Alkair et al. (2023). A STEM

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
	Plastics and Environmental Impact	advantages and limitations of biodegradable vs. conventional plastics, describe the chemistry of plastic degradation, and propose evidence-based strategies to reduce plastic pollution in Kazakhstan.			students apply green chemistry principles to evaluate plastic materials, design a biodegradable packaging solution for a Kazakhstani food product, and calculate the atom economy of their chosen polymer synthesis.	model for engaging students in environmental sustainability programs. Applied Environmental Education & Communication, 22(1), 13-26; Hsiao & Su (2021). Sustainability, 13(7), 3772.
29	§34. Main Functiona	Students identify and name the main	1	**SCIENCE +**	Digital structure drawing and	Aroch et al. (2024). Modes of

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
	l Groups of Organic Compounds	functional groups in organic molecules (hydroxyl, carboxyl, amino, ester, amide), predict reactivity based on functional group type, and draw structural formulae of simple organic molecules.		**TECHNOLOGY**	classification: students use ChemSketch to draw organic molecules containing different functional groups, then classify them by reactivity and predict which pairs could undergo condensation reactions to form polymers.	technology integration in chemistry teaching. Chemistry Education Research and Practice, 25(3), 843-861.
30	§35. Identification of Organic Compounds	Students describe chemical tests to identify organic functional groups (bromine water	1	**SCIENCE**	Inquiry-based laboratory investigation: students use the 5E model to predict, test, and explain results for	Kennedy & Odell (2014). Engaging students in STEM education. Science

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
		for alkenes, Tollens' reagent for aldehydes, litmus for carboxylic acids), predict test outcomes for given compounds, and interpret experimental results.			unknown organic compounds, developing analytical thinking and connecting organic theory to practical identification skills.	Education International, 25(3), 246-258; Bybee et al. (2006). The BSCS 5E instructional model. BSCS.
31	§36. Genetic Relationships Between Organic Compounds	Students construct a genetic relationship diagram connecting major classes of organic compounds (alkanes → alkenes → alcohols → aldehydes →	1	**MATHEMATICS + SCIENCE**	Systems thinking and mathematical modelling: students create a visual 'organic chemistry roadmap' connecting compound classes through reaction	Thornburg (cited in Sanders, 2009). Integrative STEM education: Primer. The Technology Teacher, 68(4), 20-26;

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
		carboxylic acids → esters), write conversion equations between classes, and apply this knowledge to multi-step organic synthesis problems.			pathways, then solve multi-step synthesis problems — applying logical, sequential reasoning analogous to mathematical proof.	Stohlmann et al. (2012). J-PEER, 2(1), Article 4.
32	Organic Synthesis: Polymer Design Engineering Challenge	Students design a novel biodegradable polymer for a specified application (medical implant, food packaging, or agricultural film), justify their monomer	1	**ENGINEERING + MATHEMATICS**	Integrated STEM design challenge: students apply all unit knowledge (functional groups, polymerisation reactions, green chemistry) to an open-ended	Guzey et al. (2016). Building up STEM: An analysis of teacher-developed engineering design-based STEM

No.	Topic	Learning Objective / Outcome	Hours	STEM Component	Teaching Method	Literature Source
		selection using functional group chemistry, and calculate the degree of polymerisation needed to achieve target properties.			engineering design task, combining organic chemistry with material science and quantitative polymer mathematics.	integration. J-PEER, 6(1), 2; Moore et al. (2014). Implementation and integration of engineering in K-12 STEM education. Purdue University Press.

Normality (Shapiro-Wilk) and Homogeneity of Variance (Levene's Test)

Private School

Normality Test (Shapiro-Wilk Test)

	n	W	p
Experimental	16	0.971	0.862
Control	20	0.958	0.512

Note. *Shapiro-Wilk test of normality of post-test scores by group. p > .05 indicates normality assumption is satisfied.*

Homogeneity of Variances Test (Levene's)

	F	df1	df2	p
Post-test scores	1.243	1	34	0.272

Note. *Levene's test based on mean. Dependent variable: Post-test scores. p > .05 indicates homogeneity of variance assumption is satisfied.*

Both assumptions were satisfied for the private school: Shapiro-Wilk tests confirmed normality of post-test scores in both the experimental group (W = .971, p = .862) and the control group (W = .958, p = .512), and Levene's test confirmed homogeneity of variance (F(1, 34) = 1.243, p = .272). The use of ANCOVA is therefore justified.

State School

Normality Test (Shapiro-Wilk Test)

	n	W	p
Experimental	18	0.968	0.763
Control	21	0.972	0.814

Note. *Shapiro-Wilk test of normality of post-test scores by group. p > .05 indicates normality assumption is satisfied.*

Homogeneity of Variances Test (Levene's)

	F	df1	df2	p
Post-test scores	2.156	1	37	0.150

Note. *Levene's test based on mean. Dependent variable: Post-test scores. p > .05 indicates homogeneity of variance assumption is satisfied.*

Both assumptions were satisfied for the state school: Shapiro-Wilk tests confirmed normality of post-test scores in both the experimental group (W = .968, p = .763) and the control group (W = .972, p = .814), and Levene's test confirmed homogeneity of variance (F(1, 37) = 2.156, p = .150). The use of ANCOVA is therefore justified.

Specialized School

Normality Test (Shapiro-Wilk Test)

	n	W	p
Experimental	20	0.974	0.841
Control	22	0.966	0.621

Note. *Shapiro-Wilk test of normality of post-test scores by group. p > .05 indicates normality assumption is satisfied.*

Homogeneity of Variances Test (Levene's)

	F	df1	df2	p
Post-test scores	1.872	1	40	0.178

Note. *Levene's test based on mean. Dependent variable: Post-test scores. p > .05 indicates homogeneity of variance assumption is satisfied.*

Both assumptions were satisfied for the specialized school: Shapiro-Wilk tests confirmed normality of post-test scores in both the experimental group (W = .974, p = .841) and the control group (W = .966, p = .621), and Levene's test confirmed homogeneity of variance (F(1, 40) = 1.872, p = .178). The use of ANCOVA is therefore justified.