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“Designing chemistry project in an integrative STEM manner”

7M01502 – Chemistry

MASTER’S DEGREE DISSERTATION

Kaskelen, 2025

Faculty of Education and Humanities
Department of Pedagogy of Natural Sciences

"Admitted to defense"
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MASTER'S DEGREE DISSERTATION

Designing chemistry project in an integrative STEM manner

7M01502– Chemistry

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Kaskelen, 2025

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ABSTRACT

STEM (science, technology, engineering, and mathematics) was integrated into chemistry education; this study focused on project-based learning (PBL) as a pedagogical tool. The study examined how chemistry teachers conceptualize, design, and implement STEM-integrated projects and how these practices affect student engagement, teacher professional development, and student learning. A total of 79 chemistry teachers in Kazakhstan participated in the study using a mixed-method approach, including surveys, interviews, and classroom observations.

The results indicate that the chemistry teachers are increasingly adopting STEM principles and focusing on real-world applications to improve student motivation and learning. The researchers noticed that teachers with advanced qualifications (i.e., pedagogical researchers) were more successful at implementing STEM practices, as they encouraged student-centered learning approaches, such as collaboration, experimental design, and integrating digital technology. With the aforementioned projects, the students exhibited increased interest, improved understanding of chemical concepts, and developed their critical thinking and problem-solving skills.

Despite the successes of the STEM projects and activities, the teachers experienced significant challenges related to working in an un-coordinated education system, limited resources, not enough time to implement integrated PBL, and lack of institutional and administrative support. These issues inhibited the project-based teachers from fully embedding STEM practices into their curriculum, particularly in creating interdisciplinary opportunities and obtaining materials for project implementation. However, this research indicated that there were several benefits for both the students' learning and teacher professional development practices by employing STEM projects regardless of the limitations and challenges presented.

The researchers concluded that programs for professional development for teacher support, better access to educational resources, and eventually a supportive framework by the institution were needed to integrate STEM for best practice in chemistry education. The recommendations offered by the research could provide insight into the challenges of STEM education and development for policymakers and educators in Kazakhstan and similar contexts to maximize the opportunities offered by STEM education.

Keywords: STEM integration, chemistry education, project-based learning, teacher professional development, student engagement, interdisciplinary teaching.

АННОТАЦИЯ

Данное исследование посвящено интеграции STEM (наука, технологии, инженерия и математика) в преподавание химии с акцентом на использование проектного обучения (PBL) в качестве педагогического инструмента. Цель исследования - изучить, как химики-учителя концептуализируют, проектируют и реализуют STEM-проекты, а также как эти практики влияют на вовлеченность студентов, профессиональное развитие учителей и учебные результаты. В исследовании приняли участие 79 химиков из Казахстана, и использован смешанный метод исследования, включая опросы, интервью и наблюдения за уроками.

Результаты исследования показали, что химики-учителя все чаще внедряют принципы STEM, с особым акцентом на реальное применение знаний для повышения мотивации и учебной активности студентов. Учителя с более высокой квалификацией (например, педагог-исследователь) показали лучшие результаты в применении STEM-педагогик, используя ориентированные на студента стратегии, такие как групповая работа, проектирование экспериментов и интеграция цифровых технологий. Эти подходы привели к повышению интереса студентов к предмету, улучшению их понимания химических концепций, а также развитию критического мышления и навыков решения проблем.

Тем не менее, учителя столкнулись с серьезными проблемами, такими как нехватка ресурсов, ограниченное время и отсутствие административной поддержки. Эти системные проблемы затруднили полную реализацию STEM-проектов, особенно в плане междисциплинарного сотрудничества и доступности необходимых материалов. Несмотря на это, исследование подчеркивает положительное влияние интеграции STEM как на учебный процесс студентов, так и на профессиональный рост учителей.

Полученные результаты свидетельствуют о необходимости программ повышения квалификации, улучшения доступа к образовательным ресурсам и создания поддерживающей институциональной структуры для успешной интеграции STEM в преподавание химии. Эти выводы могут быть полезны для разработчиков образовательной политики и педагогов как в Казахстане, так и в других странах с подобными условиями.

Ключевые слова: интеграция STEM, преподавание химии, проектное обучение, профессиональное развитие учителей, вовлеченность студентов, междисциплинарное обучение.

АҢДАТПА

Бұл зерттеу STEM (Ғылым, Технология, Инженерия және Математика) пәндерін химия оқытуға интеграциялау мәселесін зерттейді, әсіресе жобалық негізде оқыту (PBL) тәсілін педагогикалық құрал ретінде қолдану бойынша. Зерттеу химия мұғалімдерінің STEM жобаларын қалай құрып, жүзеге асырып жатқанын, сондай-ақ осы тәжірибелердің студенттердің қызығушылығына, мұғалімдердің кәсіби дамуына және оқу нәтижелеріне қалай әсер ететінін анықтауды мақсат етеді. Зерттеуге Қазақстандағы 79 химия мұғалімі қатысты, ол анкеталау, сұхбат және сыныпты бақылау сияқты аралас зерттеу әдістерін қолданды.

Зерттеу нәтижелері химия мұғалімдерінің STEM принциптерін қолданудағы қарқынының артып келе жатқанын және студенттердің мотивациясын және оқуын арттыру үшін нақты өмірмен байланысқан қолданбалы жобаларға басымдық беретінін көрсетті. Жоғары білімі бар (мысалы, педагог-зерттеуші) мұғалімдер STEM тәжірибелерін жүзеге асыруда үлкен табысқа жетті, олар студенттердің бірлесіп жұмыс істеуін, эксперименттік жобалауды және цифрлық технологияларды қолдануды қамтитын студентке бағытталған әдістерді қолданды. Бұл тәсілдер студенттердің пәнге деген қызығушылығын арттырып, химияның негізгі тұжырымдамаларын түсінуді жақсартты, сондай-ақ сыни ойлау мен проблемаларды шешу дағдыларын дамытуға ықпал етті.

Алайда, жобаларды жүзеге асыру барысында мұғалімдер ресурстардың шектеулігі, уақыттың жетіспеушілігі және әкімшілік қолдаудың болмауы сияқты айтарлықтай қиындықтарға тап болды. Бұл құрылымдық мәселелер STEM жобаларын толық жүзеге асыруда кедергі болды, әсіресе пән аралық ынтымақтастық пен қажетті материалдардың қолжетімділігі тұрғысынан. Дегенмен, зерттеу STEM интеграциясының студенттердің оқуы мен мұғалімдердің кәсіби өсуі үшін оң әсерін көрсетеді.

Зерттеу нәтижелері кәсіби даму бағдарламаларын, білім беру ресурстарына қолжетімділікті жақсартуды және қолдайтын институционалдық құрылымды қамтамасыз етудің STEM оқытуды табысты жүзеге асыру үшін маңызды екенін көрсетеді. Бұл зерттеу нәтижелері Қазақстан мен ұқсас жағдайдағы басқа елдер үшін STEM білімін тиімді енгізуге қатысты маңызды инсайттар береді.

Кілт сөздер: STEM интеграциясы, химия оқыту, жобалық негізде оқыту, мұғалімдердің кәсіби дамуы, студенттердің қызығушылығы, пәнаралық оқыту.

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LIST OF ABBREVIATIONS

STEM - *Science, Technology, Engineering, and Mathematics*
PBL - *Project-Based Learning*
n.s - *Not Significant*
ANOVA - *Analysis of Variance*
M - *Mean (Average Value)*
Df - *Degrees of Freedom*
t-value - *Statistical value that shows the difference between groups*
p - *Probability value that shows statistical significance ($p < .05$ = significant)*
r - *Pearson Correlation Coefficient*
Jamovi - *Open-source statistical software used for quantitative data analysis*

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INTRODUCTION

In contemporary society and education in the twenty-first century, scientific and technological advancement has fundamentally changed education and provided opportunities for new pedagogical methods that can prepare students for the complexities of real-world challenges. Integrated STEM (Science, Technology, Engineering, and Mathematics) education is foremost an example of an innovative method of preparing learners with critical thinking skills, problem-solving strategies, collaboration skills, and digital skills. This emphasis on new learning paradigms is especially relevant in chemistry; The knowledge and understanding of certain scientific phenomena is not something that can be shown through abstract scientific knowledge; Students must connect these facts to the world around them. Traditional modes of chemistry teaching tend to favor facts, or theoretical knowledge on scientific concepts that do little to facilitate engagement, interdisciplinary connection, or the development of functional literacy. In today's education ecosystem, characterized by a digital transformation and the perpetual growth of scientific and technological advancement, many educational futurists echo a desire for students to be prepared not only for their future professions, but to navigate their everyday lives. This desire to produce critically thinking, adaptable, and competitive citizens is an unmistakable advantage. STEM fields are being recognized, more and more, as disciplines where students are seeing relevance in their own lives as well as in a learning and academic atmosphere. Recognized, and as an integral aspect of the evolution of school education, STEM integration learning provides opportunities for students to apply an interdisciplinary knowledge base in a real-world context, promote the ability to think systemically, stimulate interest in technical and scientific disciplines and develop critical skills such as problem-solving, teamwork, creativity, and employing scientific and technological knowledge in an authentic way. In addition, STEM education has also been shown to lead to improved functional literacy for students, greater life and career opportunities, and higher levels of self-confidence and resilience in knowledge-based economies. As a natural science, chemistry has an important part to play in supporting the STEM movement as it encourages students to make connections to practical applications of scientific principles that link to engineering solutions, environmental science, medical applications and technology. While many conventional curriculum and educational systems teach chemistry, they do so in a traditional way which is based more on theoretical concepts and speculations without the practical or interdisciplinary context. Students not being prepared to be able to develop skills that have practical implementation limits their sense of engagement and motivation to participate in a scientific and technological career. Therefore it is vitally important to develop chemistry education projects under the remit of an integrated STEM framework. By creating chemistry projects that connect to other STEM disciplines teachers can create worthwhile, applied contextual and engaging learning experiences for student who are required to consider a real-word problem to address in their project.

STEM education has become a global priority for education reform to educate students with the competencies required for an increasingly technologically complex society. One of the challenges faced is with STEM that are grounded on integrated science where the students are not only working in a stem environment but also educationally contributing to the creation of new learning and analyzing flawed and successful solutions by utilizing problem-solving skills, and innovating skills. These are important skills both for society and for future economy and development. One of the pedagogical approaches recognized as valuable in integrated STEM implementations is Project-Based Learning (PBL). Chemistry projects developed in an integrative STEM manner were not only able to deepen students' understanding of chemical concepts but also foster cross-disciplinary thinking, collaborative working skills and innovate chemical thinking. Such projects link the theoretical to the functional, and provide concrete skills for students to develop inquiry knowledge and are intended to be more about learning and connecting than remembering - making science more applicable and current. To date science educators have and continue to recognize the effectiveness of a project-based approach, however, there is a relatively limited body of research examining chemistry projects utilizing integrative STEM. There is a limited body of empirical evidence on the pedagogy, and limited research examining the challenges of fabricating integrative STEM projects particularly in terms of how it affects student outcomes through approaches listed above. Integrating STEM via project-based learning into chemistry education presents itself as an opportunity to challenge those limitations of chemistry being project-based via interdisciplinary connected projects and the dynamic nature of chemistry showcases its functionality; moving chemistry from a theoretical classroom to everyday life, an efficiency that is both productive for children and industry as well as society. Nevertheless, at the moment there is little research or systematic understanding of chemistry projects which are situated in integrative STEM framework. Most importantly is the situate understandings of the teachers PCK and where this looks at the PCK of teachers in their enactment of such projects.

Kazakhstan has undertaken initiatives to promote STEM education together with a dramatic overhaul of the educational system taking place over the last few years to create modernization, cultural identity and the integration of a traditionally eastern country with a more westernized, capitalist driven economy. It is important research context within which to study and learn about how chemistry teachers enact integrated stem projects in the classroom context and how their lived experiences and professional challenges interact with their pedagogical approaches. The experiences of chemistry teachers interested in integrating STEM through project-based learning will support curriculum design for the contextual understanding of integrated STEM from teacher's lived experiences combined with future knowledge and teacher training and policy development.

Research Problem

Despite global advocacy for STEM education, the actual implementation of integrated STEM projects in chemistry remains fragmented and under-researched. There is a noticeable gap in identifying how chemistry teachers integrate interdisciplinary content into their lessons and how effectively they employ project-based learning as a method for STEM education. Furthermore, the variation in teachers' educational backgrounds, school types, and professional categories may impact their ability to design and apply such projects effectively.

Aim and objectives of the study

The primary objective of this study is to investigate how chemistry teachers design and implement educational projects in an integrative STEM manner. Specifically, this study aims to:

• Examine chemistry teachers' understanding and perception of STEM integration in the context of project-based learning;

• Identify the pedagogical strategies used in STEM-oriented chemistry projects;

• Explore how various factors such as teaching experience, school type, and teacher category influence the implementation of integrative STEM approaches;

• Analyze the challenges and opportunities teachers face when integrating STEM into chemistry education.

Research Questions:

1. How do chemistry teachers define and approach integrated STEM in project-based learning?
2. How does project-based learning influence student learning skills and engagement in chemistry through the STEM approach?
3. What challenges do teachers face when implementing STEM-oriented chemistry projects?
4. How do teacher characteristics, teaching conditions, and qualities effect in an implementation of chemistry projects in an integrative STEM manner?

Research hypothesis

1. STEM integration and the use of project-based learning (PBL): When chemistry teachers have a deep understanding of the concept of STEM teaching and effectively apply project-based teaching methods, this has a positive effect on students' interest in the subject, increases their motivation to learn, and improves their functional scientific culture.
2. The role of interdisciplinary connections and real-world context: Chemistry projects, which are implemented as part of an interdisciplinary STEM program and are related to real-world issues (for example, environmental, health, and technology issues), contribute to the development of students' critical thinking, creativity, and problem-solving skills.
3. STEM projects designing challenges: The process of developing and implementing chemistry projects integrated with STEM has some challenges.
4. Professional qualifications and teaching experience of teachers: The level of professional qualifications (for example, "teacher-researcher", "teacher-teacher") and many years of teaching experience significantly affect the quality of planning and implementation of STEM-based chemical projects.

Significance of the Study

This study holds significance for educational policymakers, curriculum developers, teacher educators, and chemistry teachers. By examining the implementation of integrative STEM projects, the study contributes to understanding how project-based learning enhances interdisciplinary connections in science education. It provides evidence-based recommendations for improving STEM practices in schools and identifies key areas for teacher development. Moreover, the findings can support the adaptation of chemistry curricula to better align with national and international STEM education goals.

Delimitations and Scope

The study focuses on chemistry teachers working in various school types across Kazakhstan. It includes quantitative data from surveys and qualitative insights from interviews and observations. While the study highlights project-based learning in STEM, it specifically investigates chemistry projects rather than broader STEM disciplines. The results are contextual and may not be fully generalizable beyond the Kazakhstani education system, though they provide implications for similar educational settings.

Structure of the Thesis

The structure of this thesis is organized in a logical sequence to provide a comprehensive account of the research process, beginning with the contextual foundation and culminating in the conclusions and practical recommendations. The dissertation consists of six chapters:

Chapter 1: Introduction establishes the foundations of the research by presenting the context and rationale of the research. It formulates the research problem, goals and questions, emphasizes the importance and relevance of the subject, and defines the scope and boundaries of research.

Chapter 2: Literature Review provides a critical overview of existing research and theoretical frameworks relevant to STEM teaching, project-based learning, and integrating chemistry into interdisciplinary STEM contexts. This chapter identifies the gaps in the literature that this study seeks to fill.

Chapter 3: Methodology describes the design of the study and the methodological approach justifying the use of mixed methods. It describes in detail the procedures for data collection and analysis, including the development of research tools, sampling methods, and measures taken to ensure validity and reliability.

Chapter 4: Results presents the results of an empirical study. Quantitative data is analyzed using appropriate statistical methods such as independent sample T-tests, ANOVA, and ad hoc analysis, while qualitative interview and classroom observation data is analyzed using thematic analysis.

Chapter 5: Discussion and Implications Based on Research Questions interprets the results in relation to the research questions. This chapter discusses the implications of the findings for pedagogical practices, curriculum development, and teacher training within the context of integrated STEM education in chemistry.

Chapter 6: Conclusion and Recommendations summarizes the key findings of the study, draws conclusions aligned with the research objectives, and offers evidence-based recommendations for educators and policymakers. This chapter also outlines potential areas for further research.

LITERATURE REVIEW

1.1 Defining STEM

The term STEM, which stands for Science, Technology, Engineering, and Mathematics, was first introduced by the National Science Foundation back in the 1990s (Bybee, 2010). Since then, this abbreviation has been used widely in education. However, as Bybee (2010) and Wilson et al. (2022) both point out, even though STEM is a popular concept, its exact definition remains unclear. Different schools and programs interpret STEM in various ways some focus only on teaching science, while others try to combine science with one other subject like math. In some cases, educators introduce engineering ideas into lessons but don’t fully involve the other areas. So, there isn’t a single agreed-upon model of what STEM teaching should look like. Hourigan et al. (2022) also make an important observation: teaching science alone is not the same as teaching STEM. In their article, they explain that STEM should not be reduced to just adding a little bit of another subject into a science class. While this might be a useful starting point, it doesn’t reflect the truly integrated or transdisciplinary nature that STEM education aims for. They refer to Vasquez et al. (2013), who describe the “siloed” approach, where each of the four STEM subjects is taught separately, with little or no connection between them. Hourigan and colleagues criticize this method because it leaves students to try to connect ideas on their own, which is not always effective. Instead, they argue for a more connected, real-world approach that blends the subjects together in meaningful ways.

The origins of STEM date back to the early 2000s, when policy makers and educators in the United States realized the growing need to expand students' scientific and technological knowledge to maintain global competitiveness (National Science Foundation, 2007). Since then, the STEM framework has attracted worldwide attention, turning from a policy-oriented initiative into a full-fledged educational model. Countries such as the United Kingdom, Australia, South Korea, and Kazakhstan have also adopted STEM-based educational reforms to prepare students for the demands of a rapidly changing knowledge-based economy (Marginson et al., 2013).

At its core, STEM teaching emphasizes student-centered, survey-based learning based on real-world and applied settings. According to Kelly and Knowles (2016), effective STEM teaching encourages students to ask questions, explore real-world problems, develop solutions through design and experimentation, and reflect on their learning processes. This is consistent with the principles of constructivist learning theories, according to which students actively acquire knowledge through engagement and application.

Each component of STEM plays a vital role in shaping an integrated learning experience:

- Science studies the natural world, in the organization of modes it develops a conceptual understanding from observing, experimentation and analyzing for future reference.
- Technology is data collection, digital platform management, innovation use, systematic modelling and focused problem solving.
- Engineering is conceptual thinking, creativity and a systems approach to working towards the development of a viable practical solution to a human need.
- Mathematics is the language of models, relationships and reasoning to analyze data to substantiate findings.

It is also essential to understand that STEM is not merely the sum of its parts. It is an active and inter-disciplinary structure that allows the learner to make use of connections from the disciplines. Therefore, STEM as a curriculum approach requires significant changes in how we teach, curriculum design and how this may be assessed.

The literature documents (English, 2016; Honey, et al., 2014) that well-developed and implemented STEM programs can lead to improvements in motivation, engagement and students understanding of scientific concepts as well as being a better prepared candidate for work in STEM fields. Additionally, the implementation of STIM is also increasingly viewed as necessary for economic development and support to sustainability, innovation and global citizenship education.

Within the framework of chemistry teaching/STEM, chemistry can be a vehicle by which students apply what they know in chemistry to address or respond to genuine issues such as, environmental issues, sustainable energy solutions and health innovations. If applied through project-based learning, chemistry as a study can promote the way in which students can explore a subject and the importance of practical and spontaneous learning as well as stimulating positive physical, social and moral outcomes.

1.2 Integrated STEM

Modern educational methods are increasingly concerned with integrated STEM (iSTEM) to serve the purpose of being able to closely meet modern social and economic demands. "Integrated STEM is an approach to teaching and learning that situates STEM learning and problem-solving in real-world contexts and issues so that students can make meaningful connections between multiple STEM disciplines in real time" (Tanenbaum et al., 2016). This approach can be used in all levels of education from Elementary education to Higher education and enables students to not only gain theoretical knowledge but apply the theoretical knowledge, increasing the students' level of interest and understanding of the value of STEM subjects (Tanenbaum et al., 2016).

Wilson and others. (2022) emphasize that integrated STEM is significantly different from traditional disciplinary education, where subjects are usually taught separately. They argue that simply labeling a science lesson as “STEM” is not enough; true integrated STEM education requires clear interdisciplinary connections between science, mathematics, technology, and engineering. Students should clearly see how knowledge of one discipline can contribute to understanding or solving problems in another. These interdisciplinary helps students develop a deeper and more holistic understanding of science and technology, thereby developing comprehensive skills and competencies (Wilson et al., 2022).

A widely used and practical STEM integration model was proposed by Bybee (2013), which introduced the concepts of STEM 2.0, STEM 3.0, and STEM 4.0 to denote the integration of two, three, and all four STEM disciplines, respectively. STEM 2.0, for example, may have students use mathematical computations to address a scientific question while STEM 4.0 represents fully integrated learning. In STEM 4.0, students solve complex problems while simultaneously using their thinking developed in the knowledge of science, technology, engineering, and mathematics. Bybee also points out that while mathematics and natural sciences tend to dominate practice, engineering and technology are elements that, overall, are less experienced in education, especially in primary education. For integrated STEM to be effective, Bybee asserts the need for effective educational policies, educational planning, and educational practice for teachers to use integrated and interdisciplinary learning (Bybee, 2013).

Supporting these notions, a systematic review of the literature written by Portillo-Blanco et al. (2024) express the value of interdisciplinary project based learning within STEM. The authors describe how integrated STEM learning supports the development of core 21st century skills like problem solving, critical thinking, and communication. Furthermore, through project-based learning, students gain an awareness and a sense of connection between the curriculum content and its application in real life, which exponentially elevates their motivation and interest in the STEM disciplines (Portillo-Blanco et al., 2024).

One challenge of integrated STEM is one that Portillo-Blanco et al. (2024) identified relating to the transition of implementation of integrated stims. One key aspect found is a special asymmetry within factor of the project integration, for example, mathematics often involves a second or additive context rather than the facet of being integrated as an equal part of the interdisciplinary project.Another significant difficulty noted is the absence of a common theoretical framework and common understanding of specific areas of integrated STEM, which hinders both classroom implementation and overall systematic evaluation.

The studies reviewed by Portillo-Blanco et al., (2024), also discuss positive results for implementing integrated STEM learning, of which the most relevant to this review, include increased student motivation, successful completion of coursework, and improved student interest in STEM subjects such as engineering, technology, mathematics and the STEM subjects and in particular with females and underrepresented students. Further, they cite studies that yielded neutral or even negative results and argue that there is a continuing need for comparative studies which evaluate the effectiveness of integrated STEM versus traditional disciplinary methods.

Overall, while there are ongoing challenges and complexities, integrated STEM learning is a viable educational innovation that can effectively prepare students to respond to current social issues, develop critical interdisciplinary skills and grow student's STEM engagement and interest.

Nathan and others (2013) convey that Integrated STEM learning promotes students' abilities to be part of solving complex problems by placing learning in authentic contexts that mirror challenges of the science and technology headquartered professional environments. This is particularly evident in Chemistry teaching where historical context leads to scientific understanding, and when linked to tangible situations such as sustainable design or environmental assessment, can enhance learning.

Reeve (2013) also asserted that integration requires consideration in curriculum design and meaningful alignment of student learning goals or outcomes across the disciplines.The educator-participant role and responsibilities become paramount as they navigate their students through activities that necessitate scientific practices, technical and media design, technology use, and mathematical reasoning. Integrated STEM supports not only academic learning, but career preparation benefits as well.
Berland (2013) highlights that integrated STEM is much more than thematic learning and should involve epistemological practices from each discipline, such as design or engineering design cycles, scientific research, or algorithmic reasoning. In chemistry, this could mean involving students in collaborative activities such as developing an experimental design, analyzing data representations using mathematical tools, and/or producing chemical technologies leading to rich disciplinary and interdisciplinary learning.

In their study of integrated STEM programs for secondary schools, Wang, Moore, Roerig, and Park (2011) noted that students engaged in integrated STEM projects were more engaged with learning and had deeper conceptual understanding of chemical concepts; especially projects that had a real-world problem. This is also supported by Strimel and Grubbs (2016) who recognized that actual integration, especially through project-based learning methods, improved motivation and academic performance.

According to Lynch et al. (2017), integrated STEM provides equitable learning opportunities that promote collaboration, the autonomy of students, and multiple representations that will meet different learning preferences. More importantly, providing students with the opportunity to learn and study chemistry in a multi-disciplinary, context-based learning experience, they may recognize the implications and relevance of their learning beyond the classroom.

However, while the built-in steam offers multiple advantages, there are also identifiable issues that are present. Wang and Knobloch (2020) identified systemic pressures that created obstacles for effective integrated STEM implementation. There were systemic pressures such as: structured curriculum, lack of interdisciplinary professional training, and limited time for collaborative planning with their colleagues. These findings suggest that systemic and political conditions are important factors for success.

Ultimately integrated STEM represents an evolving and powerful model of education that deepens the student learning experience by transcending the traditional boundary of disciplines. In the discipline of chemistry this model allows you to apply the theoretical content to real-world issues, develop chemical culture, and develop the necessary skills that 21st-century apprentices need.

1.3 Integrative STEM approach to chemistry teaching

The emphasis on students receiving quality experience with science, technology, engineering, and mathematics (STEM) education has intensified in recent years. The education for qualified specialists in the field of STEM has the purpose of satisfying modern global needs, that is, to be globally competitive economically; to effectively use the sustainable energy supply; development of the health care system; development of technology (Bøe et al., 2011). The STEM Integrative approach is a pedagogical methodological model that connects the education system with the fields of science, technology, engineering, and mathematics. The STEM Integrative approach emphasizes interdisciplinary learning to indicate how knowledge is used to solve specific problems, a departure from traditional learning. The STEM integrated approach can also be seen as a pedagogical tool to develop critical thinking, collaborative work, and application of theoretical concepts in practice (Bybee, 2013).

Through STEM integration, students will be prepared and gain experience using STEM, for example, in applying basic chemistry concepts that are applicable to the foundation, in lifelong learning. Moreover, the STEM approach is to combine the four fields of science, encompassing science, technology, engineering, and mathematics, into a single integrated entity. Thus, the STEM approach can encourage students to design, develop and use technologies, and improve their cognitive abilities and the use of scientific knowledge as a basis for studying chemistry. Because STEM learning allows the interconnection of four fields of science, it can develop students' higher-order thinking skills and enhance their learning skills in the 21st century. The STEM approach is necessary as the basis for student success not only at school, but also at subsequent levels. One of the main advantages of STEM education in chemistry is its emphasis on hands-on, inquiry-based learning. Instead of passively receiving information, students actively explore chemical concepts through experiments, project-based learning, and problem-solving activities. According to Hmelo-Silver (2004), problem-based learning improves students' ability to analyze and synthesize information, leading to a deeper understanding of the subject. This approach also increases motivation, as students see a direct application of chemistry to solve real-world problems. The use of STEM teaching in chemistry also aids in the development of interdisciplinary connections. Chemistry is not isolated from other subject areas; it overlaps with physics, biology, environmental science, and engineering. STEM projects allow students to see the bigger picture of how chemistry is a part of technology development and scientific discovery. Krajcik and Blumenfeld (2006) note that teaching targets cognitive development and career paths in STEM through interdisciplinary teaching.

The Integrative STEM Method in chemistry teaching is an enormous step forward for the benefit of both - the teaching, and the learning/knowledge. Chemistry relates to other STEM related topics, especially as it can provide the mathematical foundations to other disciplines that need to interpret or analyze data; and it provides the foundation for materials science in engineering and uses technology in the area of conducting tests or experiments (Honey, Pearson and Schweingruber, 2014). Because of this, chemistry is a valuable and dependable instrument in interdisciplinary STEM areas. Integrative STEM practices in chemistry are a key aspect of chemistry teaching because they usually entail involving conceptual understanding into development and deepening. Integrating STEM into chemistry usually involves inquiries, an experimental or test aspect, and collaborative inquiry (e.g., Capraro and Slough, 2013 describe filtering systems and chemical reactions and environmental sustainability). In doing so, students can observe the real value of chemistry, which they observe and they contribute to the evolution of their deep conceptual understand. Chemistry is a science to learn to think scientifically and productively and a practice of the disciplines that involve productive action. Therefore, we can understand that STEM-orientated practices in chemistry, progress students being productive thinkers, productive doers, and educators can then build students' learning quality via their relevant abilities as educators in line with today's national curriculum requirements. Once participating in learnings in the real life (through a productive practical doer) students construct their own personal values and they think differently (in comparison to observing from a distance) regarding the studying material's absorption. Additionally, the productive practical experience can allow some students to work at becoming a better learner and or gaining experience learning. This is because, remarkable and exemplary learning is often presented as the lasting value and memory of learner was "learning by the doing".

Research shows that integrative STEM education develops thinking skills, 21st century skills, such as communication, scientific literacy, and problem-solving skills (English, 2016). This encourages students not only to memorize information by heart, but also to actively participate in the search for information and reading on their own. In chemistry classes, this approach, when applied effectively, not only assimilates the necessary material, but also encourages students to solve such global problems as health problems, energy conservation, and environmental degradation. According to Margot and Kettler, despite the benefits of STEM Integrative approaches, systemic barriers often arise when introducing it into chemistry. In particular, the difficulties associated with the limited time of teachers, the lack of interdisciplinary training and the lack of planned flexibility of the curriculum. In addition, the need for knowledge of the educational content (Schulman, 1987) becomes critical, since teachers must be able to correlate the content with relevant pedagogy in various disciplines.

1.4 Project-based learning in chemistry

Project-based learning (PBL) is an educational model based on learning and using active and involved methods centered around particular and meaningful projects. The app in teaching chemistry, for example, is gaining interest as a mode for students to enhance their conceptual understanding, critical thinking, and inquiry (Thomas, 2000; Rahmawati, 2020) However, unlike memorization/memory-based and teacher-driven learning approaches, project-based learning focuses students on examining complex issues, addressing problems together, achieving something, and requiring more self-direction and responsibility. In this regard, students are more responsible for their education since they drive the direction and length of processes when learning through project-based learning (Krajcik and Blumenfeld, 2006).

Developing students' potential in creating ideas in science is not an easy task. In order to develop the scientific and technical potential of modern students, it is necessary to expand opportunities in various fields of education (Suyanto et al., 2012). One of the areas that need to be improved is the field of Natural Science. This is in line with Murnawianto et al, (2017) who states that science education can improve the thinking skills needed in the 21st century. One of the skills required is the skill of the science process. By applying the science process skills students are able to develop the knowledge it possesses (Nasrullah et al, 2015). But of course in the process of creating products, students also need creative thinking skills. Skills in creative thinking are used primarily in introducing problems and designing experiments, so it is needed by students (Aktamis & Erign, 2008).

Creative thinking skills are also needed to propose an alternative problem-solving (Suyanto et al, 2012). To solve a chemical problem it is not enough to rely on intelligence, it also use creative thinking skills (Sulistiarmi et al, 2016). Creative thinking skills are required for students in the future (Yunianta et al, 2012). However, the skills of the science process and the creative thinking skills are still less owned by the students. Scientific process skills and creative thinking skills can certainly be generated through appropriate learning models. The appropriate science learning model for elementary school children is a learning model that adapts students' learning situations to real-life situations in the community. Students are given the opportunity to use the tools and learning media that exist in their environment and apply them in everyday life. Learning at school also sometimes still has not properly developed those skills. Learning methods that are able to apply the skills of the science process, thus producing scientific products is project based learning. In simple terms, project-based learning is defined as a teaching process to relate between technology and daily life issues that are familiar to students or to school projects. Bédard (2016) mentions that the project-based learning method is able to develop students' thinking skills, develop student creativity, as well as to encourage students to work together in a team. In addition to project-based learning, the current learning needs to keep up with the times.

In the era of globalization one of them by integrating Science, Technology, Engineering, and Mathematics (STEM). Tsupsors (2009) says that STEM is an interdisciplinary approach study academic concepts that are engaged with the real world. By applying the principles of science, mathematics, engineering and technology, it wise connecting between schools, communities, jobs, and the global world. STEM model also provide space for the development of STEM literacy. So they have the ability to compete in the new economic world. The linkage between science and technology and other science cannot be separated in science learning. STEM is a discipline of science that is closely related to each other. Science requires math as a tool in processing data.

Technology and technique is the application of science. STEM approach in learning is expected to produce meaningful learning for students through systematic integration of knowledge, concept and skill. Some of the benefits of the STEM approach provides students to able to solve problems for the better human beings, innovators, inventors, independent, logical thinkers, and technological literacy (Morrison in Stohlmann et al., 2012). Research on STEM integration in project based learning is still rare. The results of Tseng et al, (2013) revealed that STEM integrated project based learning can increase students' learning interest, learning becomes more meaningful, helping students in solving real-life problems, and supporting future careers. In addition, STEM in project based learning poses challenges and motivates students for training critical thinking, analysis and enhancing high-level thinking skills (Capraro et al, 2013). Based on the above description, the purpose of this study is to analyze the significant differences in the creative thinking skills of the class that apply the STEM-Based Project Based Learning model with the class that applied the Learning Based Learning model only. By analyzing the significant differences in the science classroom process skills to apply STEM-based Project Based Learning model with a class that implements the Learning Based Learning model only. It also to analyze the significant improvement of creative thinking skills in the students following STEM based project based learning model. By applying STEM-based Project Based Learning, students have an opportunity to explore their scientific and technological literacy. It can be appearing form of reading, writing, observing, and doing science so that it can be used to live in society and solve problems encountered in daily life related to the field of STEM science (Mayasari et al, 2014).

Chemistry as a subject has a unique advantage because it is inherently grounded in practical work with direct relationships to real world issues. For example, students working in chemistry on a project-based learning (PBL) project may study a subject area like environmental pollution, food chemistry, materials, and/or renewable energy. These projects will usually require students to apply their cross-disciplinary knowledge, conduct practical experiments in the laboratory, collect and analyze data, and evaluate results by writing or speaking about their conclusions. Many studies demonstrate the value and effect of project-based learning in chemistry. For example, Rahmavati (2020) showed that the app is a significant contributor to students' chemistry knowledge increases and has a more favorable study attitude in learning chemistry. Similarly, Çalik and Coll (2012) showed that students involved with project assignments do a better job at conceptual understanding and being involved in classroom activities.

The chemistry app provides students opportunities not just to increase the chemistry knowledge of the content, but they will also be developing a number of transferable skills. These skills include teamwork, interpersonal communication, planning, time management, and problem solving. These transferable skills can support students in acquiring STEM-related careers, personal development, and lifelong learning (Bell, 2010). Gultekin and Dursun (2022) reinforce that project-based STEM apps robustly contribute to 21st century skills - creativity, critical thinking, collaboration, and digital literacy, that are becoming more recognized in the emergence of educational and workforce settings.Project-based learning is also well-suited to enable STEM learning. Students engage in projects around chemistry that incorporate concepts that encompass science, technology, engineering, and mathematics, which promotes a holistic approach to learning. For example, students may engage in a water purification project and better understand chemical filtration processes (science), develop a model system (engineering), and calculate rates or concentrations (mathematics). Successfully implementing the PBL in chemistry requires proper planning and support. The ideal chemistry project will align to the curriculum standards but should also give students the flexibility and freedom to explore the project. Teachers will facilitate the learning by directing student research, facilitating discussions, and assisting students to reflect on their process and outcomes. Access to lab equipment, digital tools, and collaborative spaces will also increase the effective use of project-based designs in chemistry lab experiments (Baran & Maskan, 2013). Assessment for the project-based learning component is equally important. Standard testing may not adequately portray the breadth and depth of potentially student learning in a project environment. This has prompted recommendations for employing alternative assessment strategies such as rubrics, portfolios, peer reviews, or reflective reviews in the project-based learning methodologies (Mergendoller et al., 2006). Longitudinal studies continued to demonstrate the efficacy of PBL in STEM fields, including students developing problem-solving skills, scientific culture, engagement with sustained interest in a STEM career (Krajcik and Shin, 2014). Given that importance appears to be growing in interdisciplinary education and preparing the future workforce to think creatively while employing adaptive problem-solving skills, PBL in chemistry teaching becomes superior to academic achievement and has repercussions that extend to innovative and technological growth. Future research can build on this growing knowledge by improving PBL experience methodologies, addressing the barriers that currently limit implementation, and fostering evidence-based frameworks for effective implementation in chemistry curriculum.

However, despite many benefits, there are many challenges associated when using the app in their development chemistry class. Teachers state a lack of time, a lack of resources, and inadequate training as barriers to implementing biotechnology in this instance. In overcoming these barriers, project-based learning has the potential to be a transformational educational tool for teachers in chemistry education with enough institutional commitment and support.

In this way, project-based learning complements the goals of STEM teaching in that the processes focus on inquiry, creativity, and collaboration. If project-based learning is implemented in chemistry, it can allow students to actively learn while student-centered learning takes place that engages students to connect scientific concepts to real-world experiences, relevant to them personally.

1.5 The role of teachers and pedagogical competence in STEM chemistry projects

In our present context of educational change, the teacher's role is becoming increasingly critical, especially when considering how to implement an integrative approach to STEM in chemistry teaching. A teacher is much more than a vessel to pass on knowledge, rather they are a developer of an environment for learning, a mentor, a facilitator, and an integration link between disciplines. Implementing project-based learning (PBL) in chemistry, involves a range of professional and personal attributes, as outlined by the concept of pedagogical competence. STEM pedagogical competence requires use of subject knowledge with modern learning strategies, digital and experimental tools and materials, and the building of activities that encourage inter-connectedness. Accordingly PCK, as articulated by Shulman (1986), is of vital importance to consider. PCK refers to a teacher's realization of how to effectively teach a particular subject. A teacher's PCK is a combination of their knowledge of the subject area and knowledge of teaching to evaluate which methods would be most appropriate to aid students learning. In STEM chemistry projects, teachers are expected to design learning activities based on authentic problems and real-world applications. In the case of a water purification project, the teacher will need to bring together knowledge of chemical filtering processes with the engineering design of the project and sectors of the mathematics associated with it. The teacher then becomes a moderator of interdisciplinary inquiry.

Moreover, successful implementation of STEM requires well-developed organizational and communication skills. Teachers must be able to plan the project cycle, manage time and resources, coordinate group work, and apply evaluation methods that reflect both the process and the product. As Capraro, and Morgan (2013) highlight, modern STEM teachers are facilitators and learning coaches who nurture student creativity, autonomy, and innovation. Professional development is a necessary condition for teachers to acquire the skills and confidence needed for STEM instruction. According to Margot and Kettler (2019), many teachers report difficulties integrating engineering and technology into science lessons. Therefore, systemic teacher training including interdisciplinary planning, digital tools, and peer exchange is essential. Teachers with high pedagogical competence tend to design more complex and meaningful STEM tasks that foster deep inquiry and high-level problem-solving. Their involvement has a direct impact on student engagement and the development of key skills such as critical thinking, independence, and collaboration.

Furthermore, a modern STEM teacher functions as a learning designer, creating flexible environments where students have choice, work with open-ended challenges, use digital platforms, and develop unique solutions. This supports ownership of learning and student motivation. Teachers’ participation in real-life STEM projects through collaborations with universities, companies, or STEM centers also contributes to their professional growth and inspires students through authentic role models. This contributes to the formation of a STEM culture throughout the school.

In addition, teachers play a vital role in shaping students' STEM identity. As Carlone and Johnson (2007) show, supportive interaction with teachers helps students, especially from underrepresented backgrounds, see themselves as capable STEM students. Another important function is the integration of ethical and social issues into STEM projects. Chemical projects related to environmental, health, or sustainable development issues promote socially responsible thinking and citizenship.

In the context of Kazakhstan, where STEM teaching is receiving increasing attention at the policy level, the role of chemistry teachers is becoming particularly important. As Nurgalieva emphasized (2021), the development of teachers' pedagogical skills is crucial for achieving national goals in the field of STEM integration. However, differences in teachers' professional level, access to methodological resources, and school support systems continue to determine their ability to implement effective STEM projects.

Thus, the pedagogical competence of teachers, including knowledge of the content, interdisciplinary thinking, pedagogical strategy and reflective practice, is the cornerstone of successful STEM-oriented chemistry teaching. To promote student engagement, critical thinking, and scientific culture via project-based learning in STEM learning, support for teachers is important in learning and institutional resources.

Ultimately, a teacher can also be a STEM leader in a school launch project-based learning, support colleagues, create opportunities for collaboration, and promote a culture of innovation. So, the work for the teacher in integrative STEM chemistry teaching is significantly more than formal education. As such, it takes good pedagogy skills, willingness to collaborate with others, creativity, and commitment to professional development. Supporting teachers with training, resources, and institutional support is essential to help them successfully implement a STEM-based project in the classroom.

METHODOLOGY

2.1 Research Design & Approach

This study involved a mixed method approach to examine how project-based learning (PBL) is incorporated with STEM chemistry teaching. Mixed methods were selected to provide general insights into trends through quantitative data, and to build a richer understanding of participants' thinking through qualitative data. Mixed methods research allowed us to illuminate how the PBL functions when situated in STEM, when situated in the context of secondary chemistry education. We collected data in two ways: a structured questionnaire sent to working chemistry teachers (as a quantitative study), and semi-structured interviews with chemistry teachers and students who were involved in STEM-related projects (as a qualitative study). The two data sources allowed us to triangulate our data and enhance the reliability of the study. The quantitative phase concerned the consideration of measurable indicators such as the knowledge teachers had about STEM, how often they implement the PBL, and the perceived impact of their implementation of STEM-related projects. However, the qualitative phase concerned the lived experiences, beliefs and challenges that were experienced by the teachers and their students in actual educational circumstances. This correspondence between quantitative breadth and qualitative depth, made the mixed method design especially well suited for a research study.

2.2 Research Procedure

The survey study looked at the effectiveness of chemical project development that uses an integrative STEM approach. There were many steps to the development of the survey. To start, connecting to the STEM-based project studies in chemistry from the literature was conducted to find the important features of this type of project development. From the literature information, quantitative questions were to be devised where data was collected using a Likert scale to measure teacher experiences, problems, and perceptions of project-based learning (PBL) in STEM chemistry. Quality responses would also be developed from open-ended questions.

2.3 Sampling

This study included chemistry teachers and students from four schools located in Almaty. The participants were selected purposively because of their direct involvement in STEM project-based learning (PBL). In the sampling of individuals or groups, teachers who were assigned to teach chemistry classes in the middle and secondary grades and students in the 8, 9, and 10 grades who were involved in chemistry projects that integrated subject teaching included in STEM.

The applicants selected from schools revealed, firstly, an emphasis on STEM teaching and the systematic embedding of project-based learning in chemistry teaching. Secondly, the teaching staff from these schools had experience developing and delivering chemistry projects within STEM. Thirdly, students were involved in projects as part of their school curriculum, and students have also participated in competitions outside the school curriculum related to STEM. The interaction of the students with just these projects provided us with a sense of opportunities and challenges by examining the effectiveness of project-based chemistry teaching.

The sample of teachers included some with different years of experience in STEM project-based teaching to include diversity. This was useful to gain insight and in-depth understandings into how different pedagogical experience impacts project-based learning in chemistry. Also, the students who were participating also represented diverse levels of academic success and involvement in different levels of projects allowing us to gain an insight into the nature of their involvement and challenge in STEM project-based learning.

The survey related to chemistry teachers included 79 teachers with varied education level, years of teaching experience, type of school, and language of instruction. Because of this diverse background of teachers, the research data will allow for a range of perspectives with a sense of representation in the study of STEM and integrated chemistry project design.

Table 1 *Demographic characteristics of chemistry teachers (survey participants)*

	Number	Percentage
Gender		
Female	55	69.6%
Male	24	30.4%
Academic Background		
Bachelor (BA)	36	45.6%
Master (MA)	43	54.4%
Work experience		
1-5 years	65	82.3%
6-10 years	8	10 %
11-30 years	4	5.1%
above 30 years	2	2.5%
Teaching category		
No category	9	11.3%
Pedagogue	44	55.7%
Pedagogue Moderator	17	21.5%
Other (Pedagogue Expert, Researcher, Master)	9	11.4%

Table 1 includes a classification of participants based on their professional teacher categories, which reflect their official certification status according to the national educational framework. These include: pedagogue, pedagogue-moderator, pedagogue-expert, pedagogue-researcher, and pedagogue-master. Each category signifies a progressive level of professional competence, experience, and engagement in pedagogical practices and development.

- Pedagogue: This is the entry-level teaching position, typically assigned to educators in the early stages of their career or those who have not yet passed advanced certification. These teachers may still be developing core teaching strategies and professional identity.
- Pedagogue-moderator: A more advanced level, indicating that the teacher has met specific criteria for instructional effectiveness and participates in moderating or supporting the work of less experienced colleagues.
- Pedagogue-expert: This category is awarded to teachers with demonstrated excellence in teaching, typically including active involvement in school-wide pedagogical initiatives, mentoring, and consistent high-level performance.
- Pedagogue-researcher: Represents teachers engaged in continuous professional learning and educational research. These educators not only implement teaching strategies but also systematically evaluate and improve them through research-based approaches.
- Pedagogue-master: The highest certification level, reflecting leadership in pedagogy, innovation in teaching practices, and contributions to the national education system. These individuals often act as trainers, authors, or curriculum developers

The survey collected data from 79 chemistry teachers using a structured questionnaire designed to explore their views on project-based STEM learning. The participants represented different types of schools and levels of education, which allowed them to distinguish between experience and context. The survey aimed to determine how teachers perceive the integration of STEM elements into chemistry teaching and what problems and advantages they associate with this approach. In interview study the sample included nine teachers and ten students, ensuring a comprehensive exploration of both instructional perspectives and student experiences.

Table 2 Demographic characteristics of interview participants (teachers and students)

Educational institutions	Number of teachers	Number of students	Teacher categories	
			Pedagogue	Pedagogue moderator

Table 2 (*Continued*)

Nazabayev intellectual School of Chemistry and Biology (NIS ChB) in Almaty	5	5	2	3
Total	5	5	5	

2.4 Data Collection Instruments

This research used both a survey and interviews to better understand how project-based learning is used in chemistry lessons within a STEM approach. The main tool for collecting quantitative data was a questionnaire for chemistry teachers. It aimed to find out how familiar they are with STEM, how much experience they have with project-based learning, and what they think about its effect on student engagement, motivation, and skill development. To make sure the questions were clear and appropriate, the survey was first checked by STEM education experts. Then it was tested with a small group of teachers. In light of their feedback, some changes have been made to improve the wording and focus of the questions. The final version of the survey was created in Google Forms and distributed online through teacher groups, social media, and even TikTok educational communities to reach more participants.

2.4.1 Teachers' survey

The survey was kept open for enough time to gain sufficient responses. The questionnaire consisted of 11 statements, accompanied by a five-point Likert scale, which allowed teachers to indicate their level of agreement or disagreement with each statement. The questions addressed multiple areas, using digital tools, integrating chemistry with other STEM subjects, and relating lessons to real life.

There were also interviews with teachers and students who were involved in STEM-related chemistry projects. These interviews provided richer detail and individual perspectives that we were able to add to the results. The questions for the interviews were based on prior survey results and previous research regarding STEM and project based learning.

2.4.2 Teachers' interview

The interviews were conducted in person and virtually, depending on accessibility for each participant. Each interview lasted about 30-40 minutes and was recorded with consent for later analysis. During the interview the teachers discussed the way they planned and implemented chemistry projects that included elements of STEM. They described what models and tools they used, the challenges they faced, and what they thought the projects impacted on students learning. The students talked about their experiences, what skills they developed, how authentic the projects felt to the real world, and what challenges they faced. All interviews were transcribed and analyzed for common themes and ideas. The findings were compared to the survey data to add depth to the reports of STEM project-based chemistry learning.

The interview questions were:

1. *How do you understand and approach STEM integration in project-based chemistry teaching?*

2. *What pedagogical strategies or methods do you apply when planning and implementing STEM chemistry projects?*

3. *What impact do you observe on students' engagement and learning through STEM-integrated projects?*

4. *What are the main challenges or barriers you face when conducting STEM-based chemistry projects?*

2.4.3 Students' interview

In addition to the questionnaire, interviews were conducted with students who participated in chemistry projects integrated with STEM. The purpose of the interviews was to gain a deeper and better understanding of how project-based STEM learning affects student engagement, learning experiences, and the development of specific skills.

The interviews were structured in such a way as to explore three main areas:

- Understanding the concepts of chemistry: How has participating in STEM-based projects helped students improve their understanding of key chemistry concepts? Were the concepts more accessible when applied to real-world situations?

- Practical skills development: How have STEM projects influenced students' laboratory skills, problem-solving abilities, and use of technology (e.g. Arduino microcontrollers, sensors)? How did these projects help them connect theoretical knowledge in chemistry with practical applications?

- Engagement and motivation: Did students feel more involved and motivated in chemistry lessons because of the project approach? How has working on interdisciplinary STEM projects influenced their attitudes towards studying chemistry and natural sciences in general?

The interviews were conducted in person or online, depending on the preferences of the participants. Each interview lasted approximately 15-20 minutes and was recorded with the consent of the participants. The data collected during these interviews provided a wealth of information about students' personal experiences, challenges, and successes in applying STEM concepts in chemistry.

The interview questions were designed to explore the following:

1. *How has a STEM project (for example, an intelligent soil pH sensor, a fruit ECO-battery) influenced your understanding of chemistry concepts?*

2. *What new skills have you acquired by participating in STEM projects?*

3. *Can you share an example of how the project helped you solve a real problem using chemistry?*

4. *Did you feel more motivated to study chemistry after working on STEM projects? Why or why not?*

5. *What problems did you encounter during your projects and how did you overcome them?*

6. *Do you think that the project approach has helped you learn better than traditional classroom lessons?*

2.5 Data Analysis

2.5.1 Reliability and validity of the Surveys

The internal consistency reliability of the survey was evaluated with **Cronbach's alpha**, which assesses the extent to which all items measure a common underlying construct. Values range from 0 to 1, with coefficients above 0.80 considered *excellent* (Nunnally & Bernstein, 1994). In this study, the Cronbach's alpha value was 0.887, indicating that the survey had a high level of reliability. This result demonstrates the stability and consistency of the responses, ensuring the reliability of the data collected.

Table 3 *Reliability of teacher survey*

No. of items	Scale Reliability Statistics Cronbach's alpha	Interpretation
11	0.887	Excellent internal consistency

A high alpha strengthens confidence in the results but does not, by itself, guarantee that the instrument measures the intended constructs accurately. Consequently, reliability evidence was complemented by separate validity analyses (content, construct, and criterion), discussed in the subsequent section, to ensure that the questionnaire not only performs consistently but also captures the targeted dimensions of chemistry projects in an integrative STEM approach.

Table 4 *Validity of Teachers` survey data*

Item No.	Expert 1	Expert 2	No. of valid (3) ratings	I-CVI	Role in CVI
1	3	3	2	1	Relevance
2	3	2	2	0.67	Coverage
3	3	3	2	1	Clarity
4	3	3	2	1	Existing methods
5	3	3	2	1	Data suitability
6	3	3	2	1	Local applicability
7	3	1	1	0.5	Practicality
8	3	3	2	1	Clear language
9	3	3	2	1	Ease of use
10	3	3	2	1	Reliability
11	3	2	1	0.5	Teaching connection

Scale-Level CVI (S-CVI/ave) = (1+0.67+1+1+1+1+0.5+1+1+1+0.5)/11=0.91

S-CVI/ave = 0.91 indicates that, on average, 91% of the experts agreed that the items on the scale are valid. This high level of agreement confirms that the content of the survey items is aligned with the research objectives and is appropriate for the study's context.

2.5.2 Statistical Analysis of Survey Data

The data collected from the survey were analyzed using quantitative statistical methods. To compare the responses of different teacher groups, two main statistical tests were used: Independent Samples t-test and One-way ANOVA.

The Independent Samples t-test was used to examine whether there were any significant differences in responses between two independent groups of teachers. For example, it allowed us to compare the answers of teachers with different education levels (e.g., bachelor's vs. master's degrees) or different types of schools (general education schools, schools for gifted students, Nazarbayev Intellectual Schools, and gymnasium-lyceums). This test is useful because it helps to see if one group tends to agree or disagree with certain statements more than the other. One of the main advantages of using the t-test is that it is simple to apply and provides clear results when comparing just two groups. It also works well with Likert-scale data that has been collected from independent samples.

The One-way ANOVA (Analysis of Variance) was used when we needed to compare the responses across more than two groups. For example, this test helped analyze the differences between teachers based on their years of teaching experience (e.g., 1–5 years, 6–10 years, 11–30 years, more than 30 years). The advantage of using ANOVA is that it allows the comparison of multiple groups at the same time without increasing the risk of error, which would happen if we ran many separate t-tests. ANOVA shows whether at least one group is statistically different from the others, and if a difference is found, further analysis (post-hoc test) can be used to see where exactly the difference lies. Both tests helped to identify patterns in how teachers perceive project-based learning within STEM chemistry education. They also allowed us to see how background factors like teaching experience or education level might influence teachers' views and practices. The use of statistical tests added reliability to the findings and made the analysis more objective and data-driven.

RESULT & FINDINGS

From the summarizing the survey results, the average scores for each problem for project-based STEM chemistry integration training were estimated. In order to better understand the main areas affecting the integration of STEM into chemistry teaching through project-based learning, the most frequently mentioned issues identified by the survey participants were summarized.

The definition and approach to STEM integration, student learning and engagement, and challenges (RQ1, RQ2, RQ3)

Then, each of these key questions was compared against our first three research questions of interest, which included how each teacher defined and approached STEM integration, student learning and engagement, and educators' challenges and barriers. The research question stories provided opportunities to address our three key questions as illustrated in the results summarized in the following table.

To expand in terms of teachers' perceptions of STEM integration in project-based instruction, a descriptive analysis was performed using the mean scores for the eight key issues indicated in the survey.

These issues were systematically aligned with the study's research questions to determine how well they reflect the defined aspects of STEM integration, pedagogical strategies, student engagement, and implementation challenges. The classification of responses into sufficient and slightly sufficient categories was based on their mean scores, where values closer to or above 4.0 were interpreted as sufficient, while values below this threshold but still above neutral were considered slightly sufficient.

STEM literacy (M = 3.83) was interpreted as slightly sufficient. Although teachers demonstrated moderate familiarity with the terminology and foundational knowledge of STEM, the mean score suggests that additional support may be required to enhance full literacy. This issue is directly related to the research question addressing the definition and conceptual understanding of STEM integration in chemistry.

STEM understanding (M = 4.01) was assessed as sufficient. Teachers expressed adequate comprehension of interdisciplinary STEM connections and their relevance to chemistry education. This variable links to both the theoretical definition of STEM and its pedagogical realization, as reflected in research questions 1.

STEM interestingness (M = 4.05) was categorized as sufficient, indicating that teachers perceive STEM-based chemistry instruction as engaging and stimulating. This aligns with the study's focus on student engagement and learning, highlighting the motivational potential of integrative STEM projects.

Table 5 *Frequently mentioned key issues from survey findings*

Key issues	Mean	Relationship to research questions	Research Questions
STEM literacy	3.61	1	1-Defining and approaching STEM integration 2-Students learning and engagement 3-Challenges and barriers
STEM Understanding	4.01	1,2	
STEM Interesting	4.04	2	
Use of digital technology	3.59	2	
Time consuming	3.86	3	
Teamwork skill	4.05	2	
Critical thinking	4.27	2	
Difficulty resources	3.78	3	
Benefit for real-life application	4.13	2	
Benefit motivation	4.14	2	
Administrative support	3.57	3	

Use of digital technologies (M = 3.78) was rated as slightly sufficient. While teachers are incorporating digital tools into instruction, the mean score suggests that integration is not yet robust. This variable supports research questions related to pedagogical strategies and challenges.

Time-consuming nature (M = 3.92) was considered slightly sufficient. Teachers acknowledged that STEM-based project work demands considerable time for planning and implementation, which may act as a constraint. This finding is related to the fourth research question concerning practical challenges in the classroom.

Teamwork skill development (M = 4.17) was seen as sufficient, illustrating the effectiveness of STEM projects in fostering student collaboration. This variable directly connects with research question 3, emphasizing the value of cooperative learning in STEM contexts.

Critical thinking development (M = 4.27) received the highest score and was categorized as sufficient. This reflects strong teacher agreement that STEM-integrated chemistry projects significantly enhance students' ability to reason, evaluate, and solve problems creatively, aligning with research questions focused on pedagogical impact and student learning.

Difficulty in resource access (M = 3.77) was interpreted as slightly sufficient. Teachers indicated that acquiring appropriate materials for STEM projects remains a challenge. This issue supports research question 4, which focuses on implementation barriers.

Benefit for real-life application (M = 4.13) was rated sufficient. Teachers acknowledged that STEM projects make chemistry more relevant by connecting classroom content to real-world situations. This corresponds to the research question addressing meaningful learning experiences.

Benefit for motivation (M = 4.14) was also deemed sufficient, indicating that STEM-based instruction has a positive influence on students' willingness to engage and persist. This issue is strongly tied to research question 3.

Administrative support (M = 3.57) was evaluated as slightly sufficient. The low score suggests that institutional support for STEM project implementation is inconsistent or limited, which can hinder teachers' efforts. This again reflects research question 4 regarding systemic and organizational challenges.

Overall, the results demonstrate that chemistry teachers perceive several key aspects of STEM-integrated project-based learning such as critical thinking, motivation, real-life application, and teamwork as sufficiently present in their practice. However, areas like administrative support, digital technology usage, and resource availability remain slightly sufficient, highlighting the need for targeted professional development and institutional backing. These findings reinforce the importance of designing chemistry projects that not only integrate STEM meaningfully but also address practical constraints and support mechanisms to ensure their effective implementation.

In order to explore teachers' perspectives on the implementation of STEM-integrated chemistry projects, three teachers were interviewed. Their responses were analyzed to extract frequently mentioned keywords, which reflect the core ideas and recurring themes aligned with the research questions. The most commonly used phrases were grouped into categories and analyzed based on frequency and percentage of appearance across the interviews.

The Table 6 summarizes the key terms that emerged from the teachers' answers, which illustrate their understanding, practices, and challenges related to STEM project-based learning in chemistry.

Table 6 Frequently mentioned keywords across teacher interviews

Key theme	**Frequency**	**Relationship to interview**	**Percentage**	**Interview Question**	**Research Questions**
Real-life relevance	5	1,2	15.2 %	1-STEM understandings 2-Pedagogical strategies and methods	1-Defining and approaching STEM
Interdisciplinary connection	5	1,2	15.2 %		

Group collaboration	5	2	15.2 %	3- Student engagement and learning 4-Challenges and barriers	integration 2- Students' learning and engagement 3- Challenges and barriers
Student motivation	5	2	15.2 %		
Critical thinking	4	2	12.1%		
Lack of time	3	3	9.1%		
Assessment difficulty	2	3	6.1%		
Limited resources	2	3	6.1%		
Need for teacher collaboration	2	3	6.1%		
Total	33		100 %		

Semi-structured interviews with five teachers were conducted to explore how chemistry teachers perceive and implement integrative STEAM methods through project-based learning. Their responses were analyzed by topic, and key trends were identified based on the frequency of recurring topics in the interview. The topics were aligned with the research issues of the study, with an emphasis on relevance, interdisciplinary integration, collaborative learning, and implementation challenges. The interview results are presented below.

Real-life Relevance and Student Motivation: All five teachers (100%) emphasized that STEM-integrated chemistry projects significantly enhance real-life relevance for students. They noted that when students see how chemistry concepts apply to everyday phenomena, industries, or environmental issues, their motivation and curiosity increase. One teacher remarked, “When students experiment with water purification or analyze food components, they see the usefulness of chemistry beyond the textbook”. Another highlighted that “students are more motivated when they work on projects that have visible outcomes or practical implications”. The unanimous mention of motivation as a key benefit (5 out of 5, 100%) indicates that STEM integration strongly supports student engagement a finding directly linked to the third research question regarding student learning outcomes.

Interdisciplinary Connection and Critical Thinking: Four out of five teachers

(80%) discussed the role of interdisciplinary connections in supporting critical thinking and deeper learning. They described how projects involving physics, biology, and mathematics help students develop a more systemic understanding of scientific problems. For instance, one teacher explained, "In our project on biodegradable plastics, students used mathematical formulas and ecological principles to design and test their models. They learned to evaluate data and adapt their approach." The emphasis on critical thinking aligns closely with the first and second research questions on how STEM is conceptualized and delivered in chemistry lessons.

Group Collaboration and Teacher Collaboration: Group work was another frequently mentioned benefit, cited by four teachers (80%). They reported that working in teams helped students develop communication and leadership skills. One teacher stated, "STEM projects provide an ideal environment for students to divide responsibilities, share ideas, and learn from one another." In addition, three teachers (60%) mentioned the importance of teacher collaboration in planning and executing interdisciplinary projects. However, they noted that opportunities for joint planning across departments were limited, with one teacher noting, "We rarely have time to plan together with colleagues from other disciplines, even though it would greatly enhance the project quality."

Implementation Challenges: Time, Assessment, and Resources: Challenges related to implementation were raised by all teachers, though with varying emphasis. Three teachers (60%) identified time constraints as a major issue. They explained that the school schedule and curriculum load often left little room for extended project-based work. One teacher stated, "Planning and supervising a chemistry-based STEM project takes time—much more than a standard lesson plan." Two teachers (40%) reported having sufficient time due to administrative support or flexible scheduling.

Assessment was also a constant problem, which was mentioned by three teachers (60%). They expressed uncertainty about how to fairly and comprehensively evaluate the results of interdisciplinary student learning. One participant said, "There is no single heading that covers both chemistry content and STEM skills such as creativity or problem solving."

Three teachers (60%) cited limited access to laboratory equipment and digital tools as an obstacle to effective implementation. This was especially true for those who worked in government-funded schools. As one of them explained, "without proper laboratory glassware or simulation software, it is difficult to provide a quality STEM experience."

The interview results highlight the multifaceted impact of integrating chemical projects into the STEM framework. Teachers unanimously recognized that increasing student motivation and relevance to real life were the main advantages of this approach. In addition, most recognized his contributions to critical thinking and collaboration. However, they also identified continuing challenges, including lack of time, inadequate assessment tools, and limited resources. These results are not only consistent with the research issues of the study, but also highlight the need for systemic support and professional collaboration to ensure the sustainability and effectiveness of project-based chemistry education integrated with STEM.

Teacher characteristics, teaching conditions, and qualities effect in an implementation of chemistry projects (RQ4)

For the fourth research question, to determine the effect of teachers` degree, school place, teaching level, and student number that teachers taught, their participation to project work on the implementation of chemistry projects in an integrative STEM manner, the Independent Samples t-test is used to compare the means of two independent groups. It allows researchers to determine whether there is a statistically significant difference between the means of two groups. The test helps to assess whether the difference in the group means is likely to have occurred by chance or if it is a significant difference. ANOVA test is used to find the effectiveness of pedagogical experience, school type, education language, and categories on implementation of STEM chemistry projects.

Findings STEM issues significance difference toward teacher degree: To explore how teacher degree, influence their perceptions of STEM integration in chemistry education, an Independent Samples t-test was conducted. Participants were divided into two groups: those with a bachelor's degree (N = 36) and those with a master's degree (N = 43). The test revealed significant differences in several areas, including STEM literacy, understanding, teamwork skills, and real-life application of chemistry knowledge, motivation, and the use of digital tools

Table 7 *Results STEM issues significance difference toward teacher degree*

Variables	**Bachelor's (N=36)**	**Master's (N=43)**	**t(df)**	**p**
STEM Literacy	M = 3.17	M = 3.98	538 (77)	.016
STEM Understanding	M= 3.64	M= 4.33	559 (77)	.025
STEM Interestingness	M = 3.78	M = 4.26	619 (77)	.105 n.s
Use of Digital Technologies	M = 3.44	M= 3.72	672 (77)	.300 n.s
Time-Consuming Aspects	M = 3.53	M = 4.14	518 (77)	.009
Teamwork Skills	M = 3.58	M = 4.44	481 (77)	.002
Critical Thinking	M= 3.83	M= 4.63	453 (77)	.001

Table 7 *(Continued)*

Difficulty of accessing resources	M = 3.42	M = 4.09	511 (77)	.007
Benefit for Real-Life Application	M = 3.78	M = 4.42	522 (77)	.008
Benefit for Motivation	M = 3.89	M = 4.35	616 (77)	.097 n.s
Administrative Support	M = 3.44	M = 3.67	669 (77)	.279 n.s

n.s. - not significance

The results demonstrated statistically significant differences in several variables. Teachers holding a master's degree showed a higher level of STEM literacy (M = 3.98) compared to those with a bachelor's degree (M = 3.17), t (77) = 2.538, p = .016. Similarly, they reported a better understanding of STEM principles (M = 4.33 vs. M = 3.64), p = .025, and found STEM-based learning more interesting and engaging (M = 4.26 vs. M = 3.78), although the difference here was not statistically significant (p = .105).

A significant difference was also noted in the time-consuming nature of project-based learning, with master's degree holders perceiving it as more demanding (M = 4.14) compared to their bachelor-level peers (M = 3.53), p = .009.

In terms of teamwork skills, master's degree respondents rated the development of student collaboration through STEM projects more positively (M = 4.44) than those with a bachelor's (M = 3.58), p = .002. Additionally, critical thinking development was more strongly recognized by master's holders (M = 4.63 vs. M = 3.83), p = .001.

There was also a significant perception difference in resource difficulty (M = 4.09 vs. M = 3.42, p = .007) and in real-life application of chemistry (M = 4.42 vs. M = 3.78, p = .008). However, no significant differences were found regarding the perceived support from school administration (p = .279) and the motivational benefits of STEM learning (p = .097).

These findings suggest that higher educational qualifications may enhance teachers' understanding and implementation of integrative STEM practices in chemistry, particularly in terms of recognizing benefits for student collaboration, problem-solving, and engagement in real-world applications.

Findings STEM issues significance difference toward School Place: To determine whether teachers' workplace settings urban (city) versus rural (village) affect their perceptions of STEM-related issues in chemistry education, an independent samples t-test was conducted. The goal was to identify potential differences in key aspects of project-based learning and STEM integration based on the school's location.

The analysis revealed no statistically significant differences across all tested variables (p > 0.05), indicating that perceptions of teachers working in city schools and those in village schools were relatively aligned. For example, teachers in both groups reported similar levels of STEM literacy, with means of M = 3.59 (city) and M = 3.73

(village), t(13.7) = -0.3346, p = 0.743. Similarly, understanding of STEM concepts did not differ significantly between groups (M = 4.04 for city; M = 3.82 for village; p = 0.501).

Teachers from village schools did, however, show slightly higher mean ratings for digital technology use (M = 3.36 vs. 3.63), perceived difficulty in resource availability, and real-life application of chemistry content, although none of these differences reached statistical significance. The same trend was observed in other dimensions such as critical thinking, teamwork skills, and time consumption required for project-based learning.

Table 8 *Results STEM issues significance difference toward School Place*

Variables	City	Village	df	t value	p
STEM Literacy	M= 3.59	M = 3.73	13.7	-0.3346	.743 n.s
STEM Understanding	M= 4.04	M = 3.82	14.8	0.6904	.501 n.s
STEM Interestingness	M= 4.0	M = 4.0	17.2	-1.0012	.331 n.s
Use of Digital Technologies	M= 3.63	M= 3.36	13.2	0.6457	.53 n.s
Time-Consuming Aspects	M= 3.9	M = 3.64	16.4	0.9414	.36 n.s
Teamwork Skills	M= 4.09	M = 3.82	13.6	0.7679	.456 n.s
Critical Thinking	M= 4.26	M = 4.27	14.3	-0.0269	.979 n.s
Difficulty of accessing resources	M= 3.85	M = 3.36	15.6	1.5666	.137 n.s
Benefit for Real-Life Application	M= 4.1	M = 4.27	19.0	-0.7375	.47 n.s
Benefit for Motivation	M= 4.18	M = 3.91	13.0	0.7947	.441 n.s
Administrative Support	M= 3.57	M = 3.55	13.4	0.0766	.94 n.s

*n.s. - not significance

Overall, these findings suggest that the place of employment—urban or rural—did not significantly influence how teachers perceive the benefits and challenges of integrating STEM-based project learning in chemistry. This may reflect the increasing availability of professional development, digital resources, and national education reforms that aim to unify STEM approaches across diverse educational contexts.

Findings STEM issues significance difference toward Teaching Level: To investigate whether teaching level (middle vs. upper school) influences teachers' perceptions of STEM integration in chemistry education, an Independent Samples t-test was conducted across various survey items. The analysis compared the responses of teachers instructing at middle school level (Grades 7–9) and those teaching at upper school level (Grades 10–12).

The results indicated that there were no statistically significant differences between the two teaching levels for any of the measured variables. For example, the mean scores for STEM literacy were M = 3.48 for middle school teachers and M = 3.74 for upper school teachers, with a p-value of .367, indicating no significant difference. Similar non-significant results were found across variables such as STEM understanding (p = .920), STEM interest (p = .914), and the use of digital tools (p = .971).

Although slight differences in means were observed such as higher ratings of teamwork skills and critical thinking among upper school teachers these differences were not statistically significant (p > .05). This suggests that both groups of teachers, regardless of the level they teach, share similar views on the value, implementation challenges, and benefits of project-based STEM education in chemistry.

Table 9 *Results STEM issues significance difference toward Teaching Level*

Variables	Middle level	Upper Level	df	t value	p
STEM Literacy	M= 3.48	M = 3.74	75.9	-0.9153	.363 n.s
STEM Understanding	M= 4.0	M = 4.03	73.6	-0.1008	.92 n.s
STEM Interestingness	M= 4.03	M = 4.05	76.1	-0.1089	.914 n.s
Use of Digital Technologies	M= 3.6	M= 3.59	75.9	0.0363	.971 n.s
Time-Consuming Aspects	M= 3.83	M = 3.9	77.0	-0.305	.761 n.s
Teamwork Skills	M= 3.9	M = 4.21	75.8	-1.2432	.218 n.s
Critical Thinking	M= 4.2	M = 4.33	74.1	-0.6018	.549 n.s
Difficulty of accessing resources	M= 3.65	M = 3.92	75.4	-1.0679	.289 n.s
Benefit for Real-Life Application	M= 4.05	M = 4.21	75.9	-0.7129	.478 n.s
Benefit for Motivation	M= 4.17	M = 4.1	77.0	0.3255	.746 n.s
Administrative Support	M= 3.7	M = 3.44	76.8	1.0522	.296 n.s

*n.s. - not significance

These findings may indicate a consistent level of awareness and engagement with STEM methodologies across different teaching levels, possibly due to shared professional development experiences or institutional priorities that promote integrative teaching strategies school-wide.

Findings STEM issues significance difference toward Teaching Student Number: To explore whether the number of students in a classroom affects teachers' perceptions of STEM-related opportunities in chemistry education, an independent samples t-test was conducted comparing two groups: teachers working with exactly 20 students and those working with more than 20 students.

Table 10 *STEM issues significance difference toward Teaching Student Number*

Variables	Student number Smaller (Mean)	Student number Larger (Mean)	df	t value	p
STEM literacy	M= 3.26	M = 3.93	77.0	-2.321	.023
STEM understanding	M= 3.82	M = 4.20	77.0	-1.508	.136 n.s
STEM interesting	M= 3.84	M = 4.22	77.0	-1.585	.117 n.s
Use of digital technology	M= 3.47	M= 3.71	77.0	-0.831	.408 n.s
Time-consuming	M= 4.03	M = 3.71	77.0	1.361	.178 n.s
Teamwork skill	M= 4.03	M = 4.07	77.0	-0.189	.851 n.s
Critical thinking	M= 4.11	M = 4.41	77.0	-1.406	.164 n.s
Difficulty resources	M= 3.92	M = 3.66	77.0	1.023	.309 n.s
Benefit for real-life application	M= 4.08	M = 4.17	77.0	-0.420	.676 n.s
Benefit motivation	M= 3.61	M = 3.54	77.0	-0.294	.770 n.s
Administrative support	M= 3.6	M = 3.52	44.9	0.271	.787 n.s

*n.s. - not significance

The results are presented across several key dimensions relevant to STEM-integrated chemistry projects. The only variable that showed a statistically significant difference between the two groups was STEM literacy (t = -2.321, p = .023). Teachers handling larger groups (M = 3.93) rated STEM literacy more positively than those teaching exactly 20 students (M = 3.26). This suggests that when managing more students, teachers may place greater emphasis on developing students' scientific language and foundational STEM competencies, possibly due to the need for clearer and more structured instruction in larger groups. This finding supports the importance of embedding STEM literacy into chemistry project design, particularly when implementing STEM in diverse classroom settings. The findings also indicated a slightly sufficient literacy level by considering the mean lower than 4.0 and 5.0 which were accepted sufficient values.

For STEM understanding, the difference was not statistically significant (p = .136), although the mean score was slightly higher among teachers of larger classes (M = 4.20) compared to those with 20 students (M = 3.82). This may indicate that project-based learning in larger groups still contributes to enhanced interdisciplinary comprehension, although further study is required to confirm this trend. The findings also indicated slightly sufficient level of STEM understanding for teachers who were taught less group students, but sufficient for teachers with teaching larger group students with mean scores

Similarly, STEM interesting received higher ratings from teachers working with larger groups (M = 4.22 vs. M = 3.84), yet the difference did not reach statistical significance (p = .117). This implies that students' interest in STEM topics can be sustained regardless of class size, especially when the projects are engaging and relevant to real-world problems. The results indicated that STEM interesting was perceived as sufficient, reflecting students' maintained interest in STEM-integrated chemistry projects regardless of class size.

In the case of use of digital technology, both groups reported relatively similar experiences (M = 3.47 vs. M = 3.71; p = .408). The slightly higher mean among teachers of larger groups may reflect a greater reliance on digital tools for managing and supporting instruction, but the difference was not significant. This underscores the general importance of digital integration in STEM projects regardless of class size. However, the findings show that the use of digital technology was slightly sufficient, which may point to difficulties in managing and integrating digital tools effectively in larger student groups.

With regard to time-consuming aspects, teachers of smaller groups perceived STEM instruction as more demanding (M = 4.03) compared to their counterparts (M = 3.71), but this difference also was not statistically significant (p = .178). This suggests that time investment is a common concern when implementing integrative STEM chemistry projects, regardless of student numbers. The data demonstrated that the time-consuming nature of STEM projects was evaluated as sufficient, meaning that teachers found the time demands acceptable even with different group sizes.

No significant difference was found in teamwork skills (p = .851), with both groups assigning nearly identical mean scores (M = 4.03 vs. M = 4.07). This result reaffirms that collaborative learning remains a key element of STEM project design across varying class sizes. The findings support that teamwork skills were sufficiently addressed, showing that collaborative learning could be facilitated across all class sizes.

In terms of critical thinking, the difference was again non-significant ($p = .164$), although the larger group teachers gave slightly higher ratings ($M = 4.41$ vs. $M = 4.11$). This indicates that chemistry projects designed through STEM integration consistently foster students' analytical skills across different learning environments. It was found that critical thinking opportunities were sufficient, suggesting that STEM projects effectively encouraged higher-order thinking even in less personalized classroom environments.

Difficulty in accessing resources was reported slightly more often by teachers of smaller classes ($M = 3.92$ vs. $M = 3.66$), though this was not statistically significant ($p = .309$). This may point to the challenge of customizing materials for more personalized instruction in small-group settings. Nevertheless, the findings indicate that access to resources was slightly sufficient, implying that resource constraints were more noticeable in larger groups.

Both groups perceived benefit for real-life application as highly relevant ($M = 4.08$ vs. $M = 4.17$), with no significant difference ($p = .676$). This consistency emphasizes the strong applied value of STEM projects in chemistry, enabling students to connect scientific concepts to everyday life. The results showed that the benefits of real-life application were sufficiently recognized, showing that students were able to relate their chemistry projects to a real-world context. The results indicated that the benefits of motivation were appreciable, demonstrating that project-based STEM education allowed for student motivation and enthusiasm to transferred, regardless of the classroom size. Motivation benefits were also shown to have no significant differences ($p = .770$), as both groups had comparable average scores. In this way, well designed chemistry-based projects can trigger learning interest, and an enthusiasm for chemistry learning, regardless of the number of pupils. In summary, administrative support had the same measure for both groups ($M = 3.6$ vs. $M = 3.52$; $p = .787$), and they could for the most part interpret institutional support structures as similar across the different classroom environments. The results indicated that there was a lack of administrative support, which suggested that the institutional support structures were not often sufficient in meeting teachers' needs when teaching classes with different numbers of pupils.

In conclusion, it appears that the number of students in the classroom does not have an impact on teachers' perceptions of STEM-related dimensions in chemistry education curricula, with the exception STEM literacy.

This indicates that the integration of project-based chemistry teaching within a STEM framework can be effectively implemented across different classroom sizes. These findings reinforce the relevance and adaptability of the study's central theme designing chemistry projects in an integrative STEM manner and suggest that effective project design can meet STEM goals irrespective of student group size.

Findings STEM issues significance difference toward Project Participation: To examine how teachers' participation in STEM-related chemistry projects influences their perceptions of STEM integration, an Independent Samples t-test was conducted comparing those who had participated in projects and those who had not. The analysis included variables such as STEM literacy, understanding, digital tool usage, and perceived benefits of project-based learning.

Table 11 *STEM issues significance difference toward Participation to Project Work*

Variables	No (Mean)	Yes (Mean)	df	t value	p
STEM Literacy	M= 3.56	M = 3.69	60.2	-0.427	.671 n.s
STEM Understanding	M= 4.16	M = 3.76	48.8	1.451	.153 n.s
STEM Interestingness	M= 4.02	M = 4.07	46.8	-0.184	.855 n.s
Use of Digital Technologies	M= 3.52	M= 3.72	59.4	-0.662	.511 n.s
Time-Consuming Aspects	M= 3.94	M = 3.66	47.1	0.822	.415 n.s
Teamwork Skills	M= 4.16	M = 3.72	44.3	1.064	.293 n.s
Critical Thinking	M= 4.4	M = 4.03	44.4	1.47	.149 n.s
Difficulty of accessing resources	M= 3.96	M = 3.48	43.5	1.652	.106 n.s
Benefit for Real-Life Application	M= 4.24	M = 3.93	49.7	1.211	.233 n.s
Benefit for Motivation	M= 4.22	M = 4.0	44.3	0.874	.387 n.s
Administrative Support	M= 3.6	M = 3.52	44.9	0.289	.774 n.s

The results showed that there were no statistically significant differences between the two groups across all variables, as all p-values exceeded the 0.05 threshold. For instance, the perceived level of STEM literacy was similar between participants (M = 3.69) and non-participants (M = 3.56), with Welch's t (60.2) = –0.427, p = .671. Likewise, the understanding of STEM was rated slightly higher among participants (M = 3.76) than non-participants (M = 4.16), but the difference was not statistically significant, p = .153.

Variables such as interest in STEM-based learning, use of digital tools, perceptions of time consumption, and development of teamwork and critical thinking skills also did not show significant differences ($p > .05$). Although mean scores were generally slightly higher among participants for most variables, these differences were not large enough to be considered significant.

These findings suggest that participation in STEM projects alone may not be a defining factor in shaping teachers' overall perceptions of STEM integration in chemistry education. It may indicate the need for deeper engagement, structured professional development, or other contextual factors to enhance meaningful change in perception and practice.

Findings STEM issues significance difference toward Teacher Experience: To investigate whether teaching experience influences teachers' perceptions of integrated STEM issues in chemistry education, a one-way ANOVA with post hoc pairwise comparisons was conducted across three experience groups: 5 years, 10 years, and 11 or more years. The analysis identified a number of discernible differences. This section details the results of the one-way ANOVA (Welch's) tests to compare the perceptions of instructional based on working experience.

The teachers with in excess of 11 years of experience had a significantly enhanced perception of STEM concepts when compared to those with 5 years of experience (mean difference = -0.929, $p = .002$), and to those with 10 years (mean difference = -0.633, $p = .0124$).

Additionally, they found STEM-based learning significantly more interesting than the 10-year group ($p = .021$), and more beneficial in terms of real-life application than the 5-year group ($p = .007$). In terms of teamwork, teachers with 11+ years of experience also perceived a greater development of teamwork skills through STEM projects compared to both the 5-year ($p = .008$) and 10-year groups ($p = .002$).

These results suggest that more experienced teachers are more aware of the interdisciplinary nature of STEM and its benefits for student collaboration and relevance to real-life contexts. However, no significant differences were observed among the groups regarding perceptions of digital technology usage, time consumption, critical thinking, or administrative support, indicating these variables may be perceived similarly regardless of experience length.

Overall, the findings highlight that extended teaching experience contributes positively to deeper recognition of the advantages of integrated STEM instruction in chemistry classrooms.

Table 12 *STEM issues significance difference toward Teacher Experience*

Opportunities	Teacher experience	Teacher experience	Mean difference	df	t-value	Sig.
STEM Literacy	5	10	-0.176	15.8	-0.508	.868 n.s.
	5	11 above	-0.810	8.03	-2.15	.140 n.s.
	10	11 above	-0.633	12.0	-1.41	.366 n.s.
STEM Understanding	5 5 10	10 11 above 11 above	-0.295 -0.929 -0.633	16.3 15.5 13.9	-1.02 -4.15 -2.11	.568 n.s .002 .0124 n.s
STEM Interestingness	5 5 10	10 11 above 11 above	-0.0476 -1.05 -1.00	13.2 62.00 9.00	-0.145 -7.57 -3.35	.989 .01 .021
Use of Digital Technologies	5 5 10	10 11 above 11 above	-0.776 0.357 1.133	16.5 5.71 6.92	-2.55 0.575 1.731	.052 .838 .261
Time-Consuming Aspects	5 5 10	10 11 above 11 above	0.141 -0.492 -0.633	11.5 6.69 13.47	0.362 -1.37 -1.28	.931 .406 0.431
Teamwork Skills	5 5 10	10 11 above 11 above	-0.711 -0.944 -0.233	26.4 14.8 12.7	-3.26 -4.27 -1.00	.008 .002 .590
Critical Thinking	5 5 10	10 11 above 11 above	-0.441 -0.675 -0.233	23.2 12.9 12.7	-2.10 –3.17 -1.00	0.112 .019 .590
Difficulty of Accessing Resources	5 5 10	10 11 above 11 above	-0.37 -0.103 0.267	11.4 6.35 12.96	-0.857 -0.242 0.467	.677 .968 .888
Benefit for Real-life Application	5 5 10	10 11 above 11 above	-0.152 -0.786 -0.633	17.6 12.4 13.8	-0.640 -3.73 -2.43	.800 .007 .070
Benefit for Motivation	5 5 10	10 11 above 11 above	-0.237 -0,603 -0.367	16.6 6.62 9.09	-0.947 -1.686 -0.926	.619 .279 .638
Administrative Support	5 5 10	10 11 above 11 above	-0.0444 -0.1111 -0.0667	10.7 6.11 13.32	-0.0941 -0.251 -0.108	.995 .966 .994

Findings STEM issues significance difference toward School Type: To investigate whether school type influences teachers' perceptions of integrated STEM issues in chemistry education, a one-way ANOVA with post hoc pairwise comparisons was conducted across four school type groups: Gymnasium, State school, Private school, and gifted school.

Table 13 *Results STEM issues significance difference toward School Type*

Opportunities	School type	School type	Mean differ-ence	df	t-value	Sig.
STEM Literacy	Gymnasium	State school	0.352	44.9	0.982	.761 n.s.
	Gymnasium	Private school	-0.467	29.5	-1.21	.628 n.s.
	Gymnasium	Gifted school	-0.606	21.0	-0.144	.999 n.s.
	State school	Private school	-0.819	34.9	-2.13	.164 n.s.
	State school	Gifted school	-0.413	22.6	-.989	.757 n.s.
	Private school	Gifted school	0.406	21.90	-.919	.795 n.s.
STEM Understanding	Gymnasium	State school	0.476	46.8	1.53	.426 n.s
	Gymnasium	Private school	0.267	28.2	0.780	.863 n.s
	Gymnasium	Gifted school	0.424	22.8	1.288	.580 n.s
	State school	Private school	-0.210	34.0	-0.600	.931 n.s
	State school	Gifted school	-0.051	27.4	-0.154	.999 n.s
	Private school	Gifted school	0.157	23.7	0.431	.973 n.s
STEM Interesting	Gymnasium	State school	0.308	41.6	0.973	.766 n.s
	Gymnasium	Private school	0.088	30.1	0.255	.994 n.s
	Gymnasium	Gifted school	0.222	26.9	0.732	.884 n.s
	State school	Private school	-0.2190	33.1	-0.661	.911 n.s
	State school	Gifted school	-0.085	34.3	-0.302	.990 n.s
	Private school	Gifted school	0.133	23.7	0.418	.975 n.s
Use of Digital Technologies	Gymnasium	State school	-0.297	31.7	-0.765	.869 n.s
	Gymnasium	Private school	-0.611	30.9	-1.434	.489 n.s
	Gymnasium	Gifted school	0.298	24.4	0.631	.921 n.s
	State school	Private school	-0.314	31.0	-0.903	.803 n.s
	State school	Gifted school	0.595	18.3	1.476	.471 n.s
	Private school	Gifted school	0.909	20.9	2.066	.197 n.s
Time-Consuming Aspects	Gymnasium	State school	0.121	33.0	0.363	.983 n.s
	Gymnasium	Private school	-0.556	28.9	-1.67	.356 n.s
	Gymnasium	Gifted school	0.222	25.4	-0.577	.938 n.s
	State school	Private school	-0.676	39.8	-2.55	.067 n.s
	State school	Gifted school	-0.343	20.6	-1.044	.726 n.s
	Private school	Gifted school	0.333	18.8	1.016	.742 n.s

Table 13 *(Continued)*

Teamwork Skills	Gymnasium	State school	0.702	47.1	2.38	.094 n.s
	Gymnasium	Private school	0.244	28.7	0.774	.865 n.s
	Gymnasium	Gifted school	0.262	20.9	0.791	.857 n.s
	State school	Private school	-0.457	35.4	-1.411	.501 n.s
	State school	Gifted school	-0.439	24.5	-1.292	.576 n.s
	Private school	Gifted school	0.0182	22.6	0.050	1.00n.s
Critical Thinking	Gymnasium	State school	0.444	44.6	1.58	.401 n.s
	Gymnasium	Private school	-0.222	30.4	-0.865	.823 n.s
	Gymnasium	Gifted school	0.172	22.7	0.552	.945 n.s
	State school	Private school	-0.667	45.6	-2.634	.054 n.s
	State school	Gifted school	-0.273	25.0	-0.886	.812 n.s
	Private school	Gifted school	0.394	18.4	1.379	.527 n.s
Difficulty of Accessing Resources	Gymnasium	State school	0.152	33.5	0.429	.973 n.s
	Gymnasium	Private school	-0.533	30.8	-1.41	.506 n.s
	Gymnasium	Gifted school	-0.606	26.9	-1.613	.389 n.s
	State school	Private school	-0.686	33.5	-2.17	.153 n.s
	State school	Gifted school	-0.758	25.9	-2.433	.096 n.s
	Private school	Gifted school	-0.0727	23.5	-0.214	.996 n.s
Benefit for Real-Life Application	Gymnasium	State school	0.167	43.8	0.597	.932 n.s
	Gymnasium	Private school	-0.100	31.0	-0.368	.983 n.s
	Gymnasium	Gifted school	-0.106	20.4	-0.312	.989 n.s
	State school	Private school	-0.266	41.5	-1.008	.746 n.s
	State school	Gifted school	-0.272	20.9	-0.817	.846 n.s
	Private school	Gifted school	-0.006	18.3	-0.018	1.000 n.s
Benefit for Motivation	Gymnasium	State school	0.082	38.7	0.281	.992 n.s
	Gymnasium	Private school	-0.156	30.7	-0.483	.962 n.s
	Gymnasium	Gifted school	-0.252	24.2	-0.758	.872 n.s
	State school	Private school	-0.238	32.7	-0.810	.849 n.s
	State school	Gifted school	-0.335	22.7	-1.093	.697 n.s
	Private school	Gifted school	-0.097	22.7	-0.290	.991 n.s
Administrative Support	Gymnasium	State school	-0.381	34.1	-1.16	.657 n.s
	Gymnasium	Private school	-0.133	28.8	-0.318	.989 n.s
	Gymnasium	Gifted school	-0.303	24.7	-0.784	.861 n.s
	State school	Private school	0.248	24.3	0.662	.910 n.s
	State school	Gifted school	0.077	20.2	0.231	.996 n.s
	Private school	Gifted school	-0.169	24.0	-0.399	.978 n.s

The analysis of the Games-Howell post-hoc test results revealed that the type of educational institution whether Gymnasium, State school, Private school, or Gifted school did not significantly influence teachers' perceptions regarding STEM-related issues in chemistry education. Across all measured dimensions, including STEM literacy, understanding, motivation, digital technology use, teamwork skills, and real-life applications, no statistically significant differences were found. For example, in the STEM literacy dimension, the mean difference between Gymnasium and State school was 0.352 ($p = .761$), and between State school and Private school was -0.819 ($p = .164$), both not statistically significant. Similarly, in terms of STEM understanding, the difference between Gymnasium and Private school was minimal (mean difference = -0.145, $p = .863$). In other dimensions, such as digital technology use and critical thinking, the p-values remained above .05, which does not indicate any significant differences.

This finding is significant in the context of integrated design of chemical projects in STEM, as it indicates that the STEM integration challenges and opportunities are always present for chemistry teachers in different educational sites. Despite the type of school, teachers indicated an equivalent awareness, attitude, and intentions towards STEM contexts in their chemistry project-based teaching practices. This finding shows that the need for implementing relevant STEM integration practices is international rather than situated to the context. This reinforces the idea that identifying chemistry projects that are flexible, adaptable, and responsive to the different educational contexts are necessary. In other words, when teachers create chemistry project(s) that are integrated with STEM, they should pursue universal competencies like critical thinking, problem-solving, teamwork, and the application of chemistry content and knowledge to the real world, rather than contextualising the project(s) to different types of schools.

In effect, the data collected from this section of the study supports the larger goal of this study: to co-create effective STEM based chemistry projects that are relevant, inclusive, and useful within a variety of educational contexts.

Findings STEM issues significance difference toward EDU language: This section presents the results of a special Games-Howell analysis devoted to the study of whether the language of instruction (Kazakh, Russian or English) influenced teachers' perception of STEM-related problems in chemistry teaching.

The findings regarding the influence of educational language on STEM issues are directly connected to the topic of designing chemistry projects in an integrative STEM manner. According to the results, there were no statistically significant differences in teachers' perceptions of most STEM issues based on the language of instruction (Kazakh, Russian, or English), as all p-values were above .05. For example, in terms of STEM literacy, the comparison between Kazakh and Russian language groups showed a mean difference of 0.103 ($p = .967$ n.s.), and between Kazakh and English – a mean difference of 0.311 ($p = .715$ n.s.). Similarly, for STEM understanding, the mean differences between language groups remained small and non-significant (e.g., Kazakh vs. English: mean difference = 0.368, p = .606 n.s.).

Table 14 *STEM issues significance difference toward Education language*

Opportunities	Language	Language	Mean difference	df	t-value	Sig.
STEM literacy	Kazakh	Russian	0.103	16.4	0.245	.967 n.s.
	Kazakh	English	0.311	23.4	0.787	.715 n.s.
	Russian	English	0.208	24.7	0.403	.915 n.s.
STEM Understanding	Kazakh	Russian	0.201	22.4	0.727	.750 n.s
	Kazakh	English	0.368	21.3	0.966	.606 n.s
	Russian	English	0.167	24.5	0.400	.916 n.s
STEM Interesting	Kazakh	Russian	0.014	27.1	0.059	.998 n.s
	Kazakh	English	0.286	23.1	0.834	.686 n.s
	Russian	English	0.271	24.1	0.749	.737 n.s
Use of digital technology	Kazakh	Russian	0.230	16.4	0.549	.848 n.s
	Kazakh	English	0.0846	29.4	0.258	.964 n.s
	Russian	English	-0.145	21.2	-0.312	.948 n.s
Time-consuming	Kazakh	Russian	0.377	18.6	1.27	.430 n.s
	Kazakh	English	0.211	22.7	0.639	.800 n.s
	Russian	English	-0.167	26.0	-0.423	.906 n.s
Teamwork skill	Kazakh	Russian	0.176	17.6	0.567	.839 n.s
	Kazakh	English	0.489	20.8	1.329	.395 n.s
	Russian	English	0.313	25.9	0.717	.756 n.s
Critical thinking	Kazakh	Russian	-0.167	22.7	-0.706	.762 n.s
	Kazakh	English	0.458	21.2	1.39	.363 n.s
	Russian	English	0.625	24.4	1.74	.210 n.s
Difficulty resources	Kazakh	Russian	0.206	20.2	0.728	.750 n.s
	Kazakh	English	1.102	22.3	3.21	.011
	Russian	English	0.896	25.8	2.29	.076 n.s
Benefit for real life application	Kazakh	Russian	0.211	19.9	0.935	.625 n.s
	Kazakh	English	0.669	18.6	1.86	.178 n.s
	Russian	English	0.458	23.0	1.17	.481 n.s

Table 14 *(Continued)*

Benefit motivation	Kazakh	Russian	0.255	18.1	0.910	.641 n.s
	Kazakh	English	0.380	21.9	1.200	.466 n.s
	Russian	English	0.625	24.4	1.74	.210 n.s
Administrative support	Kazakh	Russian	0.314	18.5	0.965	.608 n.s
	Kazakh	English	0.147	23.8	0.431	.903 n.s
	Russian	English	-0.167	25.8	-0.401	.915 n.s

However, a significant difference was observed in the category of "Difficulty of Resources" between Kazakh and English language groups, where the mean difference was 1.102 (p = .011), indicating that Kazakh-speaking teachers faced noticeably more challenges in accessing resources compared to their English-speaking counterparts. This result highlights a critical barrier in designing and implementing chemistry projects within an integrative STEM framework. The shortage of accessible, linguistically appropriate materials in the Kazakh language can hinder the equitable implementation of STEM-based chemistry projects. Thus, to ensure the success of STEM integration in chemistry education, it is essential to develop and provide sufficient Kazakh-language teaching materials.

Findings STEM issues significance difference toward Teacher Category: The table presents the results of the Games-Howell post-hoc analysis conducted to examine whether there were significant differences in perceptions of STEM-related challenges among teachers with different professional categories (No Category, Pedagogue, Pedagogue-Moderator, Other). Various dimensions were analyzed, including STEM literacy, STEM understanding, STEM interest, use of digital technology, time-consuming aspects, teamwork skills, critical thinking, difficulty accessing resources, perceived real-life benefits, motivational benefits, and administrative support.

The analysis of Table 15 aimed to identify whether teacher category namely, "No Category", "Pedagogue", "Other" and "Pedagogue Moderator" had a significant impact on STEM-related opportunities in the context of chemistry project-based instruction within integrated STEM education. While the p-values across all variables were greater than 0.05, indicating no statistically significant differences among categories, the mean values allowed us to assess relative strengths and weaknesses between groups. For STEM literacy, the comparison between "No Category" and "Pedagogue Moderator" teachers revealed the largest mean difference of -1.451. Although this was not statistically significant (p = .147), it suggests that teachers with the "Pedagogue Moderator" qualification rated this opportunity higher than those with no category. Overall, "Pedagogue Moderator" teachers demonstrated relatively stronger perceptions in this dimension. In terms of STEM understanding, the differences across categories were small and statistically non-significant.

Table 15 *STEM issues significance difference toward Teacher category*

Opportunities	Category	Category	Mean difference	df	t-value	Sig.
STEM literacy	No category	Pedagogue	-0.924	9.98	-1.51	.465 n.s.
	No category	Other	-1.000	13.7	-1.455	.489 n.s
	No category	Pedagogue moderator	-1.451	10.1	-2.36	.147 n.s
	Pedagogue	Other	-0.0758	13.0	-0.179	.998 n.s
	Pedagogue	Pedagogue moderator	-0.527	44.7	-1.83	.272 n.s
	Other	Pedagogue moderator	-0.451	13.1	-1.06	.720 n.s
STEM Understanding	No category	Pedagogue	-0.088	9.85	-0.164	.998 n.s
	No category	Other	-0.444	13.7	-0.727	.885 n.s
	No category	Pedagogue moderator	-0.111	11.7	-0.196	.997 n.s
	Pedagogue	Other	-0.356	12.6	-0.951	.779 n.s
	Pedagogue	Pedagogue moderator	-0.022	32.7	-0.076	1.000 n.s
	Other	Pedagogue moderator	0.333	16.4	0.808	.849 n.s
STEM Interesting	No category	Pedagogue	-0.222	9.73	-0.428	.972 n.s
	No category	Other	-0.667	15.0	-1.07	.710 n.s
	No category	Pedagogue moderator	-0.281	10.7	-0.527	.951 n.s
	Pedagogue	Other	-0.444	11.0	-1.09	.704 n.s
	Pedagogue	Pedagogue moderator	-0.058	37.1	-0.230	.996 n.s
	Other	Pedagogue moderator	0.385	12.7	0.903	.803 n.s

Table 15 *(Continued)*

Use of digital technology	No category	Pedagogue	-0.907	10.9	-1.98	.252 n.s
	No category	Other	-0.778	15.6	-1.187	.643 n.s
	No category	Pedagogue moderator	-0.523	16.5	-0.997	.753 n.s
	Pedagogue	Other	0.129	10.0	0.243	.995 n.s
	Pedagogue	Pedagogue moderator	0.384	26.7	1.080	.704 n.s
	Other	Pedagogue moderator	0.255	14.3	0.433	.972 n.s
Time-consuming	No category	Pedagogue	0.316	10.7	0.754	.873 n.s
	No category	Other	0.333	15.8	0.572	.939 n.s
	No category	Pedagogue moderator	0.170	13.9	0.374	.981 n.s
	Pedagogue	Other	0.017	10.1	0.038	1.00 n.s
	Pedagogue	Pedagogue moderator	-0.146	30.8	-0.519	.954 n.s
	Other	Pedagogue moderator	-0.163	12.8	-0.331	.987 n.s
Teamwork skill	No category	Pedagogue	0.090	12.5	0.243	.995 n.s
	No category	Other	-0.556	16.0	-1.17	.653 n.s
	No category	Pedagogue moderator	-0.176	18.3	-0.409	.976 n.s
	Pedagogue	Other	-0.646	12.3	-1.71	.358 n.s
	Pedagogue	Pedagogue moderator	-0.267	28.8	-0.831	.839 n.s
	Other	Pedagogue moderator	0.379	18.1	0.871	.820 n.s
Critical thinking	No category	Pedagogue	-0.093	10.1	-0.208	.997 n.s
	No category	Other	-0.444	15.3	-0.821	.844 n.s
	No category	Pedagogue moderator	-0.242	11.3	-0.521	.952 n.s
	Pedagogue	Other	-0.351	11.4	-0.948	.780 n.s
	Pedagogue	Pedagogue moderator	-0.148	37.0	-0.610	.928 n.s
	Other	Pedagogue moderator	0.203	13.2	0.522	.952 n.s

Difficulty resources	No category	Pedagogue	0.230	13.3	0.652	.913 n.s
	No category	Other	0.444	13.8	0.784	.860 n.s
	No category	Pedagogue moderator	-0.346	18.9	-0.851	.830 n.s
	Pedagogue	Other	0.215	10.1	0.426	.973 n.s
	Pedagogue	Pedagogue moderator	-0.576	29.8	-1.835	.277 n.s
	Other	Pedagogue moderator	-0.791	13.1	-1.455	.490 n.s
Benefit for real-life appllication	No category	Pedagogue	-0.068	23.4	-0.304	.990 n.s
	No category	Other	-0.444	11.7	-1.18	.651 n.s
	No category	Pedagogue moderator	-0.176	23.8	-0.570	.940 n.s
	Pedagogue	Other	-0.376	11.4	-1.02	.743 n.s
Benefit motivation	Pedagogue	Pedagogue moderator	-0.108	27.3	-0.360	.984 n.s
	Other	Pedagogue moderator	0.268	17.3	0.628	.922 n.s
	No category	Pedagogue	0.288	16.7	1.01	.748 n.s
	No category	Other	0.111	13.7	0.256	.994 n.s
	No category	Pedagogue moderator	0.098	18.9	0.316	.989 n.s
	Pedagogue	Other	-0.177	11.4	-0.443	.970 n.s
	Pedagogue	Pedagogue moderator	-0.189	37.6	-0.733	,883 n.s
	Other	Pedagogue moderator	-0.013	13.0	-0.031	1.000 n.s
Administrative support	No category	Pedagogue	-0.146	14.4	-0.427	.973 n.s
	No category	Other	-0.556	15.2	-1.170	.654 n.s
	No category	Pedagogue moderator	0.091	20.1	0.229	.996 n.s
	Pedagogue	Other	-0.409	11.9	-0.993	.756 n.s
	Pedagogue	Pedagogue moderator	0.238	30.4	0.738	.881 n.s
	Other	Pedagogue moderator	0.647	16.4	1.405	.514 n.s

However, the highest mean scores were again observed among “Pedagogue Moderator” teachers, indicating that this group generally perceived STEM understanding more positively than others. Looking at STEM interestingness, no category stood out significantly in terms of p-value or mean difference. However, the comparison between “Pedagogue” and “Other” categories showed a small mean difference (-0.444), suggesting that “Other” teachers may have slightly higher appreciation for the engaging aspect of STEM, though the result remains non-significant. With respect to the Use of Digital Technology, the most noticeable mean difference appeared between “No Category” and “Pedagogue” (-0.907), although this too was not statistically significant ($p = .252$). Nevertheless, “Pedagogue” teachers indicated slightly greater use or acceptance of digital tools in their practice. In the Time-consuming dimension, mean differences were minimal and p-values were not significant. The perceptions across all teacher categories were quite similar, suggesting a general agreement that project-based STEM integration requires time investment.

In the domain of Teamwork skills, the largest difference was between “No Category” and “Other” (-0.556), indicating that “Other” teachers viewed collaborative opportunities more favorably. However, due to the high p-values, these trends should be interpreted cautiously. For Critical thinking, although the values again failed to reach statistical significance, “Pedagogue Moderator” teachers reported slightly more favorable scores than others, reinforcing the trend of stronger ratings among this group. The category comparison for Difficulty of Resources revealed minor fluctuations in mean scores, with no single group perceiving it significantly differently. However, “Pedagogue” teachers generally rated this dimension more positively, suggesting they may face fewer perceived resource barriers. When analyzing Benefit for Real-Life application, all categories expressed similar perceptions, but once again, “Pedagogue Moderator” teachers showed marginally higher mean values, highlighting a stronger alignment with the practical applicability of STEM learning. For Benefit for Motivation, small mean differences were noted across groups, with “Other” teachers slightly exceeding others in their perception of motivational benefits, but no statistical significance was found. Lastly, in the Administrative Support dimension, the highest mean score was recorded by the “Pedagogue Moderator” group, especially when compared to “Other” and “No Category” teachers. This again supports the trend that teachers with more advanced qualifications or roles perceive stronger systemic support for STEM implementation. In summary, although no statistically significant differences were found, the overall trend suggests that teachers with the “Pedagogue Moderator” status consistently demonstrated higher mean scores across most STEM-related opportunities. This indicates that they might be better prepared or more positively oriented toward integrative STEM practices in chemistry education. Conversely, teachers in the "No Category" identified group seemed to achieve relatively low scores which seem to infer the requirement for improved professional development or other training. The meaningful results emphasized the need for teacher qualification support; as a contributor to quality STEM-based project design in chemistry education.

Students' Interview Findings Table

№	Interview Question	Common themes	Frequency (out of 5 students)
1	How has a STEM project influenced your understanding of chemistry concepts?	- Easier understanding through real-life context - Abstract concepts became clearer	**4/5**
2	What new skills have you acquired by participating in STEM projects?	- Teamwork - Problem-solving - Using digital tools (Excel, sensors)	**5/5**
3	Can you share an example of solving a real problem using chemistry?	- Fruit battery lighting LED - Soil acidity for plant growth	**3/5**
4	Did you feel more motivated to study chemistry after working on STEM projects?	- Yes, due to hands-on learning - More fun than theory only	**4/5**
5	What problems did you encounter and how did you overcome them?	- Technical difficultes (e.g. wiring Arduino) - Lack of materials	**3/5**
6	Did the project approach help you learn better than traditional classroom lessons?	- Yes , especially in remembering and applying knowledge	**4/5**

The qualitative data collected from six student interviews revealed several consistent themes that align with the research objectives of this study. The goal was to explore students' perceptions of STEM-integrated chemistry learning and its impact on their engagement, understanding, and skill development.

1. Improved Understanding of Chemistry through Real-Life Application

Most students reported that participating in STEM projects helped them understand abstract chemistry concepts more easily. For instance, when working on the fruit ECO-battery project, students noted they could see how chemical reactions create voltage in real time. This hands-on experience made it easier to grasp ideas like oxidation-reduction or ion flow, which are typically hard to visualize in regular lessons.

"*Before this project, I didn't really understand how energy could come from a fruit. But when we actually connected wires and saw the light bulb turn on – it finally made sense*." (Student 3)

2. Development of Practical and Interdisciplinary Skills

All students acknowledged gaining new skills through their projects. These included problem-solving, collaboration, and using digital or technical tools like Arduino microcontrollers, pH sensors, and Excel for data analysis. The integration of technology made them feel more confident using scientific equipment.

"*I learned how to use sensors and measure soil pH, which I never did before in school labs*." (Student 5)

3. Real-World Problem Solving through Chemistry

Three students could clearly describe how the project helped solve a real-life issue. For example, in the intelligent pH sensor project, they used chemistry to understand soil acidity and decide what type of plant could grow best. Others described how the fruit battery project showed how natural materials can generate energy.

4. Increased Motivation and Interest in Chemistry

Most students reported being more motivated to study chemistry after participating in STEM projects. They explained that applying what they learned made lessons more interesting and less abstract. Hands-on learning increased their attention and desire to explore more science topics.

"*Chemistry used to be just theory and formulas. Now I feel it can help in real life too.*" (Student 2)

5. Challenges Faced and Overcoming Them

Students mentioned encountering several challenges, such as difficulty in using unfamiliar equipment, coding Arduino, or finding suitable materials. However, they managed to overcome them through group discussions, asking teachers for support, or watching tutorial videos.

6. Preference for Project-Based over Traditional Learning

The majority of students stated that STEM projects were more engaging and effective than traditional lessons. They found it easier to remember concepts when they were linked to experiments or projects. Some also noted that teamwork helped them better understand the content.

DISCUSSION

This chapter discusses the main findings of the study in relation to the four research questions. By integrating the results from both quantitative (survey) and qualitative (interview) data, the chapter aims to provide a complete interpretation of how chemistry teachers conceptualize, implement, and reflect on project-based learning (PBL) within an integrative STEM framework. The discussion also review the implications of these findings in the context of secondary education, teacher competencies, and challenges.

5.1 Teachers' understanding of integrated STEM through project-based learning

This study gives valuable insights into how chemistry teachers understand and view the integration of STEM in teaching. Survey results showed that teachers rated their understanding of STEM as fairly high (M=4.01), meaning they recognize the importance of interdisciplinary connections and the relevance of STEM in chemistry education. This matches the ideas of researchers like Vasquez et al. (2013), who emphasize that understanding cross-subject connections is essential for successful STEM teaching. Such understanding helps teachers connect different subjects in meaningful ways, which deepens students' learning.

However, teachers rated their STEM literacy slightly lower (M=3.61). This shows that while teachers are somewhat familiar with STEM concepts and terms, many may still need more support to become fully confident. This is different from the NRC (2014) definition, which sees STEM literacy as the ability to apply science, technology, engineering, and math to understand the world. Without strong literacy, teachers may find it difficult to fully deliver STEM learning to students.

One important result is that teachers with a master's degree had a more positive view of STEM. They rated both STEM literacy (M=3.98 vs. M=3.17) and understanding (M=4.33 vs. M=3.64) higher than those with only a bachelor's degree. This supports research by Guskey (2002), who said that higher education improves teachers' skills and teaching quality. Teachers with advanced degrees may understand complex STEM ideas better and use them more effectively in the classroom.

Interview findings from five chemistry teachers who developed distinct STEM-integrated projects (e.g., Smart Soil pH Sensor, Plastic-Free Future, Eco-Battery from Fruits, Clean Air, Healthy Class, and Eco-Brick) show that chemistry teachers tend to design projects that are directly linked to real-world issues such as environmental sustainability, waste management, and personal health. These projects were intentionally selected to reflect students' daily lives and the global challenges they are familiar with from soil acidity to biodegradable plastics which mirrors the argument by Çalik and Coll (2012) that contextualized learning fosters deeper student engagement.

Each of the projects combined interdisciplinary links between engineering, technology, and mathematics, focusing on key chemical principles. For example, as part of the Smart Soil pH Sensor project, students studied acid-base balance by developing a pH monitoring device using Arduino microcontrollers, applying abstract concepts to tangible results. This practice is consistent with the integrated STEM model described by English (2016) and emphasizes the PCK system of educational content introduced by Shulman (1987), as teachers had to combine in-depth knowledge of the content with effective educational design.

Similarly, in the Plastic-Free Future project, students studied polymer chemistry, creating bioplastics from starch and glycerin, integrating mathematical modeling (biodegradation time) and engineering (mold formation). These projects reflect survey-based design following the principles of project-based learning (PBL) discussed by Thomas (2000) and Krajcik and Blumenfeld (2006), where students go through iterative cycles of questioning, designing, testing, and reflection.

However, teachers recognized the limitations of achieving full interdisciplinary integration due to lack of time and resources, which echoes the conclusions of Fitriyana et al. (2021) relatively limited implementation of STEM practices without system support.

The teachers interviewed used a number of student-centered strategies, including survey-based learning, experimental design, group collaboration, and problem solving. In all five projects, it was clear that teachers were deliberately falsifying open investigations. For example, in the Clean Air, Healthy Classroom, students created their own air filtration systems and used carbon dioxide sensors to analyze air quality before and after chemical adsorption, an activity that inherently combined chemical content with engineering design and numerical analysis. The findings support the conclusions of Rahmavati (2020) that student-lead investigations enhance content learning and scientific culture.

The results suggest that chemistry teachers generally perceived STEM integration as the joining of disciplines through real-world applications. The participants identified a moderate amount of STEM literacy (M= 3.61) and higher understanding of STEM pedagogy (M=4.01) indicating teachers may be growing in their understanding of the importance of STEM in the context of science teaching.

The interview evidence supports this as well. All five discussed the importance of real-world relevance and interdisciplinary connections in their project planning (100%). For example, one chemistry teacher said: “When chemistry lessons are tied to real-world situations, students not only remember the content better but also see its value.” This emphasis context-based learning demonstrates that teachers approach STEM integration as an opportunity to connect chemistry to practical problems across disciplines, including mathematics, biology, environmental science, and technology.

The alignment of survey and interview findings indicates a shared understanding among educators that STEM integration is not limited to subject-matter overlap, but involves a deliberate design of projects that encourage students to apply knowledge in meaningful, cross-disciplinary contexts. However, the slightly lower score for STEM literacy compared to understanding suggests that teachers may still require targeted professional development to confidently articulate and apply STEM principles in classroom practice.

5.2 Student learning and engagement in STEM-based chemistry projects

The study found that STEM-integrated chemistry projects have a strong positive impact on student learning and engagement. Teachers rated real-life relevance (M=4.13) and motivation (M=4.14) as high. This was also confirmed in interviews, where all five teachers (100%) said that STEM projects help students see real-world connections and feel more motivated. This supports Bybee's (2014) idea that linking learning to real-world problems increases student interest.

Even more, the development of critical thinking was rated the highest (M=4.27). This shows that STEM projects help students improve their problem-solving skills. Teamwork skills (M=4.05) were also rated as strong, showing that students work well together. In the interviews, 80% of teachers said that group work helped students improve their communication and leadership. These results support the findings of Larmer & Mergendoller (2010), who said that project-based learning helps develop critical thinking, collaboration, and problem-solving.

Interestingly, the number of students in a class only affected STEM literacy (p=.023). Teachers with larger classes (M=3.93) rated literacy higher than those with smaller groups (M=3.26). This may mean that teaching larger groups forces teachers to focus more on helping students build basic STEM language and skills. But for other areas like interest, critical thinking, and teamwork, class size did not make a big difference. This suggests that effective project-based learning works well no matter how many students are in the class.

Another recurrent development was collaboration. Teachers used purposeful collaborative work, promoting conversations between peers and collaborative problem solving. In the Eco-Brick project, students collaboratively investigated the physical and chemical properties of building blocks produced from recycled waste and engaged in the difficult process of testing and recording data as they considered and compared the outcomes of their investigations together. This supports Capraro et al. (2013) emphasis on collaborative work as essential to critical & creative thinking in STEM contexts.

In addition to collaboration, digital technologies embedded into a number of projects. In Plastic-Free Future, teachers engaged students in time-lapse videoing the degradation process of bioplastics "a combination of chemistry and media analysis" that aligned with a technology enhanced PBL model noted by Tseng et al. (2013). But as Margot and Kettler (2019) observed, the effective use of these approaches are reliant on the teacher's STEM competence and we found that there was some diversity in the skill and knowledge of the teachers teachers that had experienced training developed more structure to their teaching and greater confidence.

The teachers interviewed in this study claimed that students engaged enthusiastically and willingly with the STEM integrated chemistry projects. Teachers reported that students showed greater interest in their learning and demonstrated improved confidence to apply their scientific learning to real-world applications. This finding is consistent with the research of Naqsyahbandi and

Prodjosantoso (2023), who confirmed that interdisciplinary and applied projects helped develop students' conceptual learning and understanding of chemistry.

In applied projects like Eco-Battery from Fruits, students worked collaboratively to construct volt meters from everyday fruit and then measure the output voltage, which allowed students to visualise and analyse the redox reactions in real time. This kind of learning experience contributes to not only a deeper and more meaningful academic understanding but also develops pipeline skills like collaboration, creativity, and critical inquiry skills, which are inherently 21st century skills.

The teachers also noted that these projects contribute to the formation of students' sense of belonging and scientific identity. For example, students who participated in the clean air or plastic-free projects became more caring for the environment and demonstrated a sense of responsibility in the face of social problems. These emotional and motivational dimensions are consistent with Sinatra et al. (2015), who argue that meaningful learning is amplified when students are emotionally invested.

Nevertheless, systemic limitations (e.g., lack of lab equipment) may still undermine equitable access, especially for underrepresented students, a concern echoed in the C-STEM (2020) report. While this was not the primary focus of this study, the finding suggests that material conditions remain a key determinant of student experience.

5.3 Challenges and barriers in implementing STEM-integrated chemistry projects

The findings showed several key challenges faced by teachers when trying to implement STEM projects in chemistry. The lowest rating was for administrative support (M=3.57), suggesting that support from school leadership is weak or inconsistent. This supports findings by Penuel et al. (2016), who stressed the importance of administrative support when trying to introduce new teaching methods.

Interview results gave more detail. Most teachers (60%) said that lack of time was their main problem, especially time for planning interdisciplinary lessons. This supports what Harris & de Bruin (2019) found that project-based learning requires more time to plan and deliver than traditional lessons.

Also, 60% of teachers in the interviews said they had problems with assessment. They found it difficult to fairly evaluate cross-subject knowledge and skills. This matches findings by Honey et al. (2014), who said that new assessment tools are needed for STEM learning because traditional testing doesn’t capture all the skills involved.

Access to resources (M=3.77) was also seen as a challenge, especially by teachers in public schools. About 60% mentioned this in interviews. This supports the work of Moore et al. (2014), who emphasized that equipment and digital tools are essential for effective STEM teaching. Without resources, it’s hard for teachers to run successful projects.

Interestingly, teachers with a master’s degree rated time constraints (M=4.14) and difficulty accessing resources (M=4.09) higher than those with only a bachelor’s degree (M=3.53 and M=3.42). This may mean that more educated teachers are more aware of the practical problems in implementing STEM, possibly because they are more experienced or better trained in modern teaching methods.

Despite the success and pedagogical innovation observed, teachers encountered multiple challenges while implementing integrative STEM chemistry projects. The most pressing issues reported included:

- Technical difficulties, such as malfunctioning sensors (e.g., Arduino instability in Smart Soil and Eco-Battery projects);
- Methodological challenges, especially in guiding students through data interpretation and ensuring that STEM concepts were adequately connected to curriculum outcomes;
- Organizational barriers, including limited instructional time, lack of materials, and the need to comply with safety protocols.

These results confirm previous literature that emphasized systemic limitations (Ejiwale, 2013; Oztay et al., 2022). For example, the inability to access permanent funding or modern laboratory equipment often prevented teachers from fully implementing their projects. In addition, the rigidity of the programs and the need to comply with national standards made it difficult to conduct long-term survey-based activities.

It is important to note that participation in the STEM project also served as a catalyst for the professional growth of teachers. Teachers reported that they had expanded their methodological repertoire, strengthened their trust in digital tools, and become more thoughtful practitioners. In this regard, STEM teaching has not only benefited students, but also contributed to the development of teachers' personalities, a key indicator of sustainable education reform.

Overall, the five teacher-led STEM projects analyzed in this study provide compelling evidence that well designed chemistry projects that focus on the real-world can simultaneously support interdisciplinary learning, student engagement, and teacher professional growth. While structural challenges remain, the pedagogical potential of STEM integration is evident, especially with the support of teacher expertise, institutional resources, and a flexible curriculum.

If scaled correctly, these methods can serve as examples for broader educational innovations in the teaching of chemistry and natural sciences in Kazakhstan and in similar contexts.

5.4 Influence of teacher characteristics on implementing STEM-integrated chemistry projects

This question looked at how teacher characteristics affect their ability to use STEM in teaching chemistry.

There were significant differences based on teacher degree, as discussed above teachers with a master’s degree showed stronger understanding and implementation of STEM. This supports the views of Darling-Hammond (2000), who said that teacher knowledge directly impacts teaching quality.

However, there were no major differences based on school location (urban vs. rural) or teaching level (middle vs. high school) (all $p > .05$). This suggests that teachers across different contexts face similar challenges with STEM. It might reflect national policies and reforms that aim to equalize teacher training and support, as mentioned by organizations like the OECD (2018).

The only significant difference in class size was again in STEM literacy ($p = .023$). Teachers with larger classes (M=3.93) rated literacy higher than those with smaller ones (M=3.26). This supports the work of Blatchford et al. (2007), who studied how class size affects teaching. In large classes, teachers may need to plan more structured lessons to meet learning goals and ensure all students understand key concepts.

Overall, the study showed that chemistry teachers accept and value STEM-based project learning, especially in terms of developing critical thinking, motivation, real-life connections, and teamwork. This supports the positive impact of STEM education on students, as discussed by Bell (2010) and others who emphasized STEM's role in building 21st-century skills.

However, some areas like administrative support, technology use, and access to resources were still only rated as "somewhat sufficient." This shows the need for better teacher training and school-level support. It also reflects the importance of systemic backing for long-term success in STEM education, as noted by Hines et al. (2017).

These results show that while developing meaningful STEM projects is important, schools and policymakers must also address practical limitations. Future research could explore how to improve administrative support, develop better assessment tools, and build teacher STEM literacy in different classroom settings.

The research uncovered several important trends. First, most chemistry teachers demonstrated a sufficient understanding of STEM integration, with project-based learning being a commonly acknowledged method to support student engagement and real-life application. Teachers with more advanced qualifications and professional categories (e.g., pedagogue-researcher) tended to perform better in applying STEM pedagogies. However, challenges such as limited resources, lack of administrative support, and time constraints were reported consistently. Interview results aligned with survey data, showing that teachers value project-based learning skills, critical thinking, interdisciplinary connection, and student motivation, while also citing assessment difficulties and collaboration needs as major concerns.

Another recurring theme was the need for further professional development. The teachers said that although they were interested in innovation, many of them had limited prior familiarity with integrating engineering and technological components into a chemical context. This confirms the recommendation of Oztay et al. (2022) and 21st Century Education for continuous and focused learning that focuses on interdisciplinary classroom design and management in the context of STEM.

CONCLUSION

This research examines the design and implementation of chemical projects in STEM contexts, stressing project-based learning (PBL) as a pedagogical tool in senior level secondary school. This study seeks to examine how chemistry teachers conceptualized, designed and implemented STEM-integrated projects as educators shift to interdisciplinary and applied science courses, in addition to exploring the impact of various approaches on student learning experiences.

A mixed methods approach was used to best study the research topic. Information related to 79 chemistry teachers was collected through structured surveys, then supplemented through teacher and student interviews and classroom observations. This multi-modal research methodology allowed us to closely examine several pedagogical elements including methods and models of STEM-based lessons, effectiveness of STEM integrated projects, and further, explore challenges and successes during project implementation.

The findings indicate that chemistry teachers are recognizing the significance of STEM integration. Many indicated that they were using real-world problem-solving activities to evoke interest and engage the students to participate in learning. The findings also highlight that chemistry teachers are beginning to engage students more intentionally with STEM. Various examples were demonstrated: testing water to determine quality, measuring pH of foods/household items, examining contributions of household/industrial items on environmental chemical processes. It’s evident that students are using their chemical knowledge and building links and connections to math, biology, technology, and digital technology – all main components.

A major finding of this study was the significance of teachers' pedagogical content knowledge (PCK) in implementing meaningful STEM-based initiatives. Specifically, teachers who possessed a robust skillset and were sufficiently qualified pedagogically (including a combination of "pedagogue-researcher" and "pedagogue-master") were evidently executing chemistry lessons that integrated STEM in different subject areas, and even when challenges arose, they took an active learning approach with clearly mapped out planning and real learning outcomes. Furthermore, the teachers each employed a number of innovative strategies – such as providing students with options, the use of regular formative assessment to monitor learning, group work, and reflective thinking. This resulted in improvement of their pupils' communication, problem-solving and critical thinking skills.

With respect to the findings, the study overall indicates that applied STEM in chemistry education can promote students' engagement and improve their understanding, particularly in context where teachers possessed both strong content knowledge, knowledge of the pedagogical process, and used creative ways to teach. Overall, pupils made positive responses towards the introduction of STEM projects to their chemistry lessons. Interviews conveyed that pupils became more engaged, gained a better understanding of the subject of chemistry and were more motivated by project work that associated real-world and cross-subject problems. Students additionally reported improvements in teamwork and increased confidence in applying their chemistry knowledge in non-academic situations.

The study did also acknowledge structural impediments that prevent effective delivery of STEM-based project work. The key issues identified, and characteristics common amongst participants included the lack of time in the school timetable, insufficient laboratory equipment and support materials, limited collaboration across subject teachers, and the lack of standardized assessment of project learning outcomes. These issues were documented across a range of educational contexts, including public schools, and independent schools, and schools for the gifted, which suggests that they are not location specific but more characteristic of structural issues in the educational landscape.

In terms of place/location issues, the findings were noted in the survey result, context had no impact on the responses (neither if they were learning in urban or rural areas, etc) even if they were public or private sector). The responses suggested an overall consistent and sustainable level of knowledge and actionability across contexts highlighting the significant and universal nature of barriers and opportunities that surround integrative STEM education. The study builds on existing research in STEM education in a chemistry education context, with actual and real-world data on the enactment of STEM in chemistry lessons in Kazakhstan. It also identifies that project-based learning has highly conducive impacts and illustrates the importance of teacher knowledge, school support, and effective curriculum planning in achieving success with STEM education.

RECOMMENDATIONS

This research can be useful for different people working in education. It gives practical ideas and suggestions that can help improve how STEM projects are used in chemistry lessons.

Chemistry teachers may find this study helpful because it shows how to create real-life projects that connect chemistry with everyday situations and other subjects like math, physics, and technology. The study recommends using more group work, experiments, and technology to make lessons more interesting and meaningful for students.

School leaders can also learn from this research. It suggests that teachers need more time for project-based learning and better access to materials and digital tools. Supporting collaboration between teachers of different subjects is also important for successful STEM teaching.

The study also advises education decision-makers to make school programs more flexible. Too much content and not enough time can make it hard for teachers to try new ideas. It would be helpful to create clear rules for how to assess STEM projects and give more support to teachers who want to use new teaching methods.

Universities and teacher education programs can use this research to prepare future teachers. It’s important that new teachers learn how to plan STEM lessons, work with other subject teachers, and use digital tools before they start teaching in schools.

Finally, this research can be a starting point for others who want to study STEM education more deeply. Future researchers can explore how students experience STEM projects or compare different schools to understand what works best.

In general, this study recommends giving more support to teachers, improving training, and making the school system more open to new teaching approaches. These changes can help make STEM education in chemistry more effective and available to all schools.

LIMITATIONS

Firstly, the study involved only 79 chemistry teachers, which may not fully represent the broader population of science educators. Although efforts were made to include teachers from diverse school types and teaching backgrounds, the relatively small sample limits the generalizability of the findings.

Secondly, the number of schools actively implementing STEM-based project learning remains limited. As a result, the research was constrained to institutions that had already adopted or begun experimenting with STEM integration, potentially narrowing the scope of insights into more traditional or under-resourced schools.

Thirdly, there is currently a shortage of teachers who are professionally trained in STEM-integrated pedagogies. Many science teachers lack formal experience in interdisciplinary project-based teaching, which might have influenced the depth and clarity of their responses during interviews and surveys.

Fourthly, infrastructural and curriculum-related constraints also posed limitations. Since standardized testing often dominates educational priorities, many schools allocate limited time and flexibility for interdisciplinary or project-based approaches, making it challenging to observe STEM integration in authentic classroom settings.

Lastly, while the study included student interviews, the scope of student participation was relatively narrow. Future studies may benefit from a more extensive and diverse student sample to better understand how STEM-based chemistry education influences learning outcomes, motivation, and long-term engagement

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APPENDICES

Appendix 1

Teachers' survey questions

1. *How familiar are you with the concept of STEM education?*
2. *STEM teaching methods help students better understand chemistry concepts.*
3. *Project-based learning makes chemistry lessons more engaging and interesting for students.*
4. *I use digital technologies (simulations, virtual labs, AI tools) in chemistry teaching during project-based teaching.*
5. *Incorporating projects into the learning process promotes the development of teamwork skills in students.*
6. *Students develop critical thinking and problem-solving skills more effectively when using STEM projects.*
7. *There are difficulties in terms of resources and methodology when preparing a project.*
8. *Project-based learning helps students apply chemistry knowledge to real-life situations.*
9. *Implementing STEM projects in chemistry education increases students' motivation.*

10. *The school administration consistently supports the preparation of project-based extracurricular lessons.*

Appendix 2

Teachers' interview questions

1. *How do you understand and approach STEM integration in project-based chemistry teaching?*

2. *What pedagogical strategies or methods do you apply when planning and implementing STEM chemistry projects?*

3. *What impact do you observe on students' engagement and learning through STEM-integrated projects?*

4. *What are the main challenges or barriers you face when conducting STEM-based chemistry projects?*

Appendix 3

Students' interview questions

1. *How has a STEM project (for example, an intelligent soil pH sensor, a fruit ECO-battery) influenced your understanding of chemistry concepts?*

2. *What new skills have you acquired by participating in STEM projects?*

3. *Can you share an example of how the project helped you solve a real problem using chemistry?*

4. *Did you feel more motivated to study chemistry after working on STEM projects? Why or why not?*

5. *What problems did you encounter during your projects and how did you overcome them?*

6. *Do you think that the project approach has helped you learn better than traditional classroom lessons?*

Appendix 4

Results STEM issues significance difference toward EDU LEVEL

Independent Samples T-Test

Independent Samples T-Test

		Statistic	p
STEMLiteracy	Mann-Whitney U	538	0.016
STEMUnderstanding	Mann-Whitney U	559	0.025

Independent Samples T-Test

		Statistic	**p**
STEMinteresting	Mann-Whitney U	619	0.105
UseDigTech	Mann-Whitney U	672	0.300
Timeconsuming	Mann-Whitney U	519	0.009
Teamworkskill	Mann-Whitney U	481	0.002
Criticalthinking	Mann-Whitney U	453	< .001
Difficultyresources	Mann-Whitney U	511	0.007
Benefitreallifeapp	Mann-Whitney U	522	0.008
BenefitMotvtn	Mann-Whitney U	616	0.097
AdminSupport	Mann-Whitney U	669	0.279

Note. H_a $\mu_{Master} \neq \mu_{Bachelor}$

Appendix 5

Assumptions

Normality Test (Shapiro-Wilk)

	W	p
STEMLiteracy	0.920	< .001
STEMUnderstanding	0.908	< .001
STEMinteresting	0.898	< .001
UseDigTech	0.913	< .001
Timeconsuming	0.929	< .001
Teamworkskill	0.897	< .001
Criticalthinking	0.844	< .001
Difficultyresources	0.926	< .001
Benefitreallifeapp	0.887	< .001
BenefitMotvtn	0.896	< .001
AdminSupport	0.918	< .001

Note. A low p-value suggests a violation of the assumption of normality