PERCEPTIONS AND EXPERIENCES OF PRE-SERVICE AND IN-SERVICE CHEMISTRY TEACHERS ON THE INTEGRATION OF ARTIFICIAL INTELLIGENCE

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ABSTRACT

PERCEPTIONS AND EXPERIENCES OF PRE-SERVICE AND IN-SERVICE CHEMISTRY TEACHERS ON THE INTEGRATION OF ARTIFICIAL INTELLIGENCE

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This study aims to explore the perceptions, experiences, and recommendations of Turkish pre-service and in-service chemistry teachers regarding the use of AI-based tools in chemistry education. A qualitative design and purposive sampling were used to recruit nine senior pre-service chemistry teachers at a university and ten in-service chemistry teachers from private colleges in Ankara. Semi-structured interviews were performed from October 2025 to January 2026, analysed by means of inductive qualitative content analysis and the constant comparative method. Three themes were identified: Teachers' Perceptions Towards AI in Chemistry Education, Experiences with AI-Based Tools in Chemistry Education, and Recommendations for Effective AI Integration in Education. Participants conceptualised AI as digital applications/information systems supporting rather than replacing teachers. In-service teachers mentioned generative AI tools; pre-service teachers mentioned simulations and animations. Uses included lesson planning, assessment/question generation, experiment/activity/material design, addressing misconceptions/learning difficulties, supporting teacher learning, and producing level-appropriate explanations, examples, analogies and visualisations. Participants agreed AI outputs required scientific-community verification, revision and contextualisation. Concerns

included accuracy, reliability, misunderstanding user intent, classroom integration, student reliance, reduced critical thinking, academic integrity, confidentiality and ethical use. Pre-service teachers focused on simulations, misconceptions, prompting, personal learning and university AI education, while in-service teachers focused on classroom applications, teacher responsibility, professional development, policies, infrastructure and monitoring. Recommendations included Practitioner-Oriented Teacher Training, Responsible Use by Students, Institutional Policies, Curriculum Arrangements, Infrastructure and Equitable Access. Accessing technology, professional experience, ethical awareness, contextual adaptation, responsible student use and institutional readiness were essential to integration, informing teacher education, professional development and institutional planning.

Keywords: Artificial intelligence, Chemistry education, Pre-service chemistry teachers, In-service chemistry teachers, Basic qualitative research.

ÖZ

YAPAY ZEKÂNIN ENTEGRASYONUNA İLİŞKİN KİMYA ÖĞRETMEN ADAYLARININ VE GÖREV YAPAN KİMYA ÖĞRETMENLERİNİN ALGILARI VE DENEYİMLERİ

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Bu çalışmanın amacı, Türk kimya öğretmen adaylarının ve hizmet içi kimya öğretmenlerinin kimya eğitiminde yapay zeka tabanlı araçların kullanımına ilişkin görüşlerini, deneyimlerini ve önerilerini incelemektir. Nitel araştırma deseni ve amaçlı örnekleme yöntemi kullanılarak Ankara'daki üniversiteden dokuz son sınıf kimya öğretmeni adayı ve Ankara'daki özel kolejlerde görev yapan on hizmet içi kimya öğretmeni çalışmaya dahil edilmiştir. Yarı yapılandırılmış görüşmeler Ekim 2025'ten Ocak 2026'ya kadar gerçekleştirilmiş ve tümevarımsal nitel içerik analizi ve sürekli karşılaştırma yöntemi ile analiz edilmiştir. Üç tema belirlenmiştir: Kimya Eğitiminde Yapay Zekaya Yönelik Öğretmen Algıları, Kimya Eğitiminde Yapay Zeka Tabanlı Araçlarla İlgili Deneyimler ve Eğitimde Etkili Yapay Zeka Entegrasyonu İçin Öneriler. Katılımcılar yapay zekayı, öğretmenlerin yerini almaktan ziyade onları destekleyen dijital uygulamalar/bilgi sistemleri olarak kavramsallaştırmıştır. Hizmet içi öğretmenler üretken yapay zeka araçlarından bahsetti; hizmet öncesi öğretmenler simülasyon ve animasyonlardan bahsetmiştir. Kullanım alanları arasında ders planlama, değerlendirme/soru üretimi, deney/etkinlik/materyal tasarımı, kavram yanılgılarının/öğrenme güçlüklerinin ele alınması, öğretmen öğrenmesinin desteklenmesi ve seviyeye uygun açıklamalar,

örnekler, benzetmeler ve görselleştirmeler üretilmesi yer almaktadır. Katılımcılar, yapay zekâ çıktılarının doğrulanması, gözden geçirilmesi ve bağlam içine oturtulması gerektiği konusunda hemfikirdir. Endişeler; doğruluk, güvenilirlik, kullanıcı niyetinin yanlış anlaşılması, sınıf entegrasyonu, akademik dürüstlük, gizlilik, etik kullanım gibi konuları içermektedir. Öğretmen adayları simülasyonlar, kavram yanılgıları, yönlendirme, üniversitede yapay zeka eğitimine; hizmet içi öğretmenler sınıf uygulamaları, mesleki gelişim, altyapı ve izlemeye odaklanmıştır. Öneriler arasında Uygulayıcı Odaklı Öğretmen Eğitimi, Öğrencilerin Sorumlu Kullanımı, Politikalar, Altyapı ve Adil Erişim almaktadır. Teknolojiye erişim, mesleki deneyim, etik farkındalık, bağlamsal uyum, sorumlu öğrenci kullanımı, kurumsal hazırlık, öğretmen eğitimi, mesleki gelişim, kurumsal planlama, entegrasyon açısından büyük öneme sahiptir.

Anahtar Kelimeler: Yapay zekâ, Kimya eğitimi, Kimya öğretmen adayları, Görev yapan kimya öğretmenleri, Temel nitel araştırma.

To my family, for their endless and unconditional love and support, and

to the one who quietly made every difficult step easier…

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LIST OF ABBREVIATIONS

ABBREVIATIONS

AGI: Artificial general intelligence

AI: Artificial intelligence

AIEd: Artificial intelligence in education

ANI: Artificial narrow intelligence

ASI: Artificial superintelligence

CV: Computer vision

ICT: Information and communication technology

ITS: Intelligent tutoring system

ML: Machine learning

NLP: Natural language processing

TPACK: Technological pedagogical content knowledge

CHAPTER 1

INTRODUCTION

1.1 Background of the problem

Around the world, educational systems and practices have been shaped by the rapid development of digital technologies. Of the various digital technologies that have emerged in the twenty-first century, artificial intelligence (AI) has emerged as one of the most transformative and has received increasing interest among researchers, educators and policy-makers (Holmes et al., 2019; Miao et al., 2021). AI generally means computer systems that can do tasks that normally require human intelligence. Such tasks include learning, reasoning, problem solving, decision-making and language processing (Miao et al., 2021). Recent advances in machine learning, natural language processing and generative AI increase the range of tasks that can be performed with AI and its adoption within education (Kasneci et al., 2023). This has led to an increase of research in the field of Artificial Intelligence in Education in the last 10 years which studies the role that clever technologies play in the processes of teaching learning and educational decision making (Zawacki-Richter et al. 2019). Zawacki-Richter et al. (2019) conducted a systematic review and found that the number of publications on applying AI in educational contexts has rapidly increased showing a growing interest in how different artificial intelligence technologies could be related to learning, teaching and evaluation Moreover, Holmes et al. (2019) suggested that AIEd could transform the sector by offering personalized learning, adaptive teaching and improved assessment.

Much attention is given to the educational potential of AI, but its implications are especially relevant to science education where students are expected to develop conceptual understanding, scientific reasoning, and problem-solving skills. Science education is an important pathway to developing scientifically literate people who can make informed decisions about scientific and technological issues that affect society (OECD, 2019). However, the learning of science is often difficult because of the complexity of scientific concepts and the necessity for students to understand phenomena that they cannot observe directly (Johnstone, 1991). According to Johnstone (1991), many of the difficulties experienced in learning science arise from the nature of science and the way in which science is traditionally taught. Hence, science educators have always been in search of new instructional strategies and technological tools to help students understand complex scientific concepts and processes.

Chemistry is often considered to be one of the most difficult subjects for students among the science disciplines because it requires an understanding of abstract concepts and the ability to connect multiple levels of representation (Johnstone, 1991; Taber & García-Franco, 2010). Many chemical phenomena are not observable directly, so learners need to interpret observable phenomena with particle explanations and symbolic representations such as chemical formulas, equations, and models (Johnstone, 1991). Difficulties in making sense of the connections between these representations can give rise to misconceptions, a fragmented understanding, and persistent learning difficulties (Taber & García-Franco, 2010; Taber, 2013). Therefore, for many years, the focus of research in chemistry education has been on the progress of students' conceptual understanding and the ability to visualise abstract chemical processes (Taber, 2013).

Learning chemistry is naturally difficult conceptually, and this has led to a growing interest in exploring how emerging technologies can contribute to teaching and learning chemistry. Recent advances in artificial intelligence (AI) have opened up new avenues to address some of the long-standing problems in chemistry education. In a critical review by Iyamuremye et al. (2024), it was found that AI and machine

learning technologies can be used in chemistry education, including personalised learning environments, intelligent tutoring systems, adaptive learning platforms, and virtual laboratories. According to Iyamuremye et al. (2024), these technologies could help students to acquire a better understanding of complex chemical concepts through personalised teaching and learning support as per their needs. In addition, generative AI tools such as ChatGPT have shown great promise in improving chemistry learning through critical thinking, problem solving, understanding concepts, creativity and personalised learning experiences (dos Santos, 2023). Moreover, recent studies show that AI-supported learning environments can be applied to develop interactive learning experiences and enhance students' engagement with chemistry content (Jiang, 2024; dos Santos, 2023). Thus, AI is increasingly considered a promising educational resource to help visualise abstract concepts, promote a conceptual understanding, and offer more personalised learning opportunities in chemistry education (Iyamuremye et al., 2024; Kasneci et al., 2023).

The potential advantages of using AI-based tools in education include enhancing instructional processes, improving student learning, and facilitating personalized education experiences. However, the extent to which AI-based tools are effective in chemistry education will depend upon the selection, adaptation, and implementation of these tools within the context of classroom practice. The successful implementation of educational technologies will not solely depend on the characteristics of the technology itself, but also on the teachers who are key in creating students' learning experiences (Ertmer, 2005; Tondeur et al., 2017). Teachers make numerous important decisions concerning the selection of instructional materials, the design of learning activities, the interpretation of curriculum requirements, and the utilization of digital technologies to facilitate student learning (Ertmer & Ottenbreit-Leftwich, 2010). Consequently, the success of integrating AI-based tools in chemistry education will depend not only on the availability of technological tools but also on the availability of teachers who are ready and willing to effectively and responsibly utilize these tools. Holmes et al. (2019) explicitly state that AI-supported educational environments are not designed

to replace human teaching and pedagogical decision-making; instead, they serve to enhance and supplement human teaching and pedagogical decision-making.

Teachers are crucial in implementing educational technologies, and their perceptions, experiences, and beliefs strongly influence whether and how educational technologies are adopted in educational settings. Previous research has demonstrated that teachers' perceptions of technology influence their willingness to adopt digital tools into their instructional practices and the way these tools are used to support learning (Ertmer, 2005; Teo, 2011). Likewise, teachers' experiences with educational technologies influence their judgements about the usefulness, effectiveness and practicality of these tools in the classroom setting (Scherer et al., 2019). The perceptions and experiences of teachers in the context of AI have become increasingly important, as tools based on AI are being increasingly integrated into educational settings (Kasneci et al., 2023; Miao et al., 2021). Some studies reported that teachers see AI technologies as beneficial tools for improving teaching efficiency, supporting student learning, and facilitating personalised instruction. Still, other studies raised concerns about accuracy, reliability, ethical issues, data privacy, bias, and the potential overreliance on AI systems (Kasneci et al., 2023; Miao et al., 2021). The findings suggest that understanding teachers' perceptions and experiences is important to identify the opportunities and challenges of integrating AI technologies into educational practice.

Although there has been a recent surge in AI research in education, most of the existing studies have focused on the development of AI technologies, student learning outcomes, technology acceptance, and applications in higher education settings (Bond et al., 2024; Zawacki-Richter et al., 2019).

There has been a growing interest in research on teachers' perceptions, attitudes, and readiness to integrate AI in education recently (Kasneci et al., 2023; Miao et al., 2021). However, the present literature has certain limitations. First, though pedagogical demands vary across different disciplines, most of the existing research has focused on teachers in general education settings rather than in specific subject

disciplines. Second, research in chemistry education has mostly focused on the technical applications and instructional potential of AI tools instead of the perceptions and experiences of chemistry teachers on their usage (Erümit & Özdemir Sarıalioğlu, 2025; Iyamuremye et al., 2024). In their systematic review of the use of AI in science and chemistry education, Erümit and Özdemir Sarıalioğlu (2025) concluded that there is a need for more pedagogical research on the integration of AI into teaching and learning processes due to the relatively limited research in chemistry education and its focus on technical applications. In a similar vein, Iyamuremye et al. (2024) pointed out the need for additional studies that explore the advantages and disadvantages of using AI in chemistry teaching. The results show that currently there is limited knowledge of how chemistry teachers perceive, use, and evaluate AI-based tools in the classroom.

Also, few studies have explored the integration of AI from the viewpoints of pre-service and in-service chemistry teachers. Previous research has addressed teachers' perceptions, knowledge, preparedness, or technology integration practices in isolation (Hammoud, 2025; Miao et al., 2021), leaving little room for comparing the viewpoints and experiences of teachers at different stages of their professional development. The understanding of the perspectives of the pre-service and in-service chemistry teachers is particularly important as both groups may differ in terms of their teaching experiences, technical skills, classroom responsibilities, and expectations regarding the implementation of AI in education (Alwaqdani, 2025; Erümit & Özdemir Sarıalioğlu, 2025). Moreover, there are still few studies done in the Turkish chemistry education context even though the availability and usage of AI-based tools in educational settings are increasing. Views and experiences of Turkish pre-service and in-service chemistry teachers regarding the use of AI-based tools in chemistry education, the possibilities, difficulties, and recommendations for effective integration of these technologies need to be investigated (Erümit & Özdemir Sarıalioğlu, 2025; Iyamuremye et al., 2024).

The growing use of AI-based tools in educational settings has led to new opportunities and challenges for teaching and learning across disciplines, including

chemistry education. Previous research has suggested the potential of AI technologies to support instructional processes, improve student learning, and foster personalised educational experiences. However, there is little knowledge of how chemistry teachers experience and perceive the integration of these technologies into educational practice (Erümit & Özdemir Sarıalioğlu, 2025). There is a need for more research, for example, on chemistry teachers' experiences with AI-based tools, their perceived benefits and challenges, and their recommendations for the use of AI in chemistry education. Moreover, the existing literature on the perceptions of pre-service and in-service instructors towards chemistry education is limited and the studies conducted earlier have mainly focused on each group separately (Erümit & Özdemir Sarıalioğlu, 2025).

Thus, this study aims to investigate the perceptions and experiences of Turkish pre-service and in-service chemistry teachers regarding the use of AI-based tools in chemistry education. The study aims to contribute to the growing literature on AI in chemistry education and provide insights that could inform teacher education, professional development and future educational practices by examining teachers' experiences, perceived benefits and challenges and recommendations of effective AI integration. Therefore, the present study aims to answer the following research questions:

What are Turkish pre-service and in-service chemistry teachers' perceptions regarding AI in chemistry education?

What are Turkish pre-service and in-service chemistry teachers' experiences regarding the use of AI in chemistry education?

What are Turkish pre-service and in-service chemistry teachers' recommendations for the effective integration of AI into chemistry education?

What are the similarities and differences between pre-service and in-service chemistry teachers in terms of their perceptions, experiences, and recommendations for the integration of AI-based tools in chemistry education?

1.2 Significance of the Study

Artificial intelligence (AI) is being integrated into education systems worldwide and is expected to have a significant impact on teaching and learning practices in the future. International bodies recognize that AI can be used to support teaching activities, promote student-centred learning, offer efficient management support and help educators in their professional work (Holmes et al., 2019; Miao et al., 2021). The proliferation of AI systems also poses new pedagogical, ethical and professional challenges for all educational actors to address (Kasneci et al., 2023; Miao et al., 2021). With the introduction of AI tools into our classrooms, there is an increasing need to investigate teachers' experiences and perceptions of these tools.

Recent work shows that educators are aware of the pedagogical benefits of AI; however, they often report a lack of expertise and training, and insufficient professional support for the application of AI tools in their practice (Chounta et al., 2022; Kasinidou et al., 2024). Thus, there is a need to investigate teachers' perceptions and use of AI tools to support responsible and impactful adoption in education.

The significance of studying the teachers' perspectives becomes even more evident when we consider that teachers are in a pivotal position in the deployment of ICT in the educational system. Previous studies have found that the perspectives, attitudes, and beliefs of teachers about innovative educational technologies can influence the adoption and integration of the technologies in schools (Ertmer, 2005; Ertmer & Ottenbreit-Leftwich, 2010; Tondeur et al., 2017). Similarly, in recent studies, research on the integration of AI in schools has also put an emphasis on the attitude of teachers towards this innovative technology. As Chounta et al. (2022) have observed, teachers have a positive attitude towards AI as an opportunity for education.

However, they didn't know how to use it specifically and needed more guidance on how to apply the AI tools to their lessons. Alwaqdani (2025) found that teachers

thought that AI tools could have many benefits such as saving teachers' time, helping with teaching planning, providing personalised learning and developing educational activities for students. The participants also expressed concerns about the training needs to use the AI tools, the reliability and security of AI technologies, trust toward AI technologies, and the negative effects of AI on the quality of the teaching and learning processes (Alwaqdani, 2025). Therefore, teachers' opinions and experiences could lead to an effective integration of AI in the education environment (Alwaqdani, 2025; Chounta et al., 2022), and exploring how they experience AI could support an adequate integration of this technology in the schools, including: the design of teacher education and professional training programmes and the support for solving problems related to the integration process (Ertmer & Ottenbreit-Leftwich, 2010; Miao et al., 2021).

This is a problematic issue in chemistry teaching. Chemistry education is a challenging field because it is abstract, involves several levels of representation and learners need to connect macroscopic phenomena with sub-microscopic and symbolic explanations (Johnstone, 1991; Taber, 2013). Therefore, various technologies and methods that can help chemistry teachers and students to understand chemistry concepts have been sought.

Recent reviews have indicated that AI-based tools can be used to improve students' conceptual understanding and engagement with chemistry topics in several ways, including adaptive learning environments, personalisation of learning experiences, virtual laboratories, automated feedback, personalised tutoring systems, intelligent tutoring systems, and visualised representations of chemical abstractions (Iyamuremye et al., 2024).

Additionally, AI provides teachers and students with the ability to develop personalised learning environments, enhance access to knowledge and resources, and design instructional plans (Iyamuremye et al., 2024; Kasneci et al., 2023). There has been an increasing interest in the use of AI in the teaching of science and chemistry recently. The research that has been done has focused more on

technological innovations and applications in teaching rather than the perceptions and experiences of chemistry teachers in the classroom (Erümit & Özdemir Sarıalioğlu, 2025). Therefore, research on teachers' perceptions and experiences with AI remains limited.

In addition, one of the main advantages of this study is that it is targeted at both pre-service and in-service chemistry teachers, unlike many previous studies that have been targeted at a single group of participants. As artificial intelligence is more and more influencing teaching and learning processes in schools (Kasneci et al., 2023; Miao et al., 2021) researchers are increasingly interested in teachers' conceptions of AI in different stages of the teaching career. Previous studies reported different attitudes of pre-service teachers towards AI, with some viewing positive aspects of AI application in education and some expressing a potential negative impact of AI on society and on the profession. For example, pre-service teachers identified the potential and risks and positive and negative outcomes that the implementation of artificial intelligence might have for education (Haseski, 2019). Likewise, research conducted with practicing teachers has revealed generally positive attitudes toward AI alongside concerns related to professional preparedness, ethical issues, trust, reliability, and the responsible use of AI in educational settings (Alwaqdani, 2025; Chounta et al., 2022). Taken together, these studies suggested that the attitudes and perspectives of teachers towards AI differ in different educational contexts and highlighted the importance of investigating the perceptions and experiences of both pre-service and in-service chemistry teachers so that they can have a more holistic view of the integration of AI in chemistry education (Alwaqdani, 2025; Chounta et al., 2022; Haseski, 2019).

In their study of Estonian K–12 teachers, Chounta et al. (2022) reported that teachers "have limited knowledge about AI and how it could support them in practice. Nonetheless, they perceive it as an opportunity for education" (p. 725). Similarly, Alwaqdani (2025) emphasized that "it is crucial to understand stakeholders' perceptions of AI as a tool to support their educational practice" (p. 2738). The author further argued that "exploring their perceptions can provide valuable insights

into how they perceive and interact with AIED" (p. 2738). Teachers also report low awareness of AI applications and significant demand for more training, support and guidance from their institutions for effectively utilizing AI within their teaching practices. Supporting this view, Kasinidou et al. (2024) noted that "there are concerns that educators may not have the necessary knowledge to teach AI or use AI tools effectively" (p. 315). Such results are important, because the teachers' beliefs, competencies and experiences have been shown to be critical in shaping how they use and implement educational technology in the classroom (Ertmer & Ottenbreit-Leftwich, 2010; Tondeur et al., 2017). While the literature has explored teachers' perceptions towards AI, very little research has explored the perspectives of both pre- and in-service teachers together. Understanding the perceptions of and engagement with AI by pre-service and in-service teachers can help to deepen the knowledge of the evolution of AI-related beliefs, knowledge, expectations, opportunities and challenges at various points in the teachers' career trajectories (Miao et al., 2021). This knowledge can be used by teacher educators, professional development organisations and educational institutions to design instructional programs that address the needs of both novice and experienced chemistry teachers (Chounta et al., 2022; Kasinidou et al., 2024).

The findings of this study are expected to make a contribution to the professional development, teacher training and generally the emerging field of research on the use of AI in chemistry education. The study could explore the experiences and perceptions of pre-service and in-service chemistry teachers on the use of AI-based tools in their classes, identify how AI technologies could be better used to the benefit of teaching and learning of this subject, the challenges involved and possible future directions. Therefore, prior research has pointed out the importance of understanding educators' conceptions of AI, in order to understand how educators will interact with AI-based tools within the learning and teaching process, and to successfully integrate them into actual teaching practice (Alwaqdani, 2025).

This knowledge will be beneficial for designing training programs that foster AI literacy, encourage pedagogical and effective application of AI and the appropriate utilization of AI-based technologies (Kasinidou et al., 2024; Miao et al., 2021).

The findings of the study could inform educational institutions and professional development providers about areas where educators might need further support, guidance and training to appropriately incorporate AI-based tools into their educational practice (Alwaqdani, 2025; Chounta et al., 2022). Furthermore, it is hoped that this study contributes to the growing literature on the role of artificial intelligence in chemistry education. Recent studies suggest that there is a need for pedagogical research to integrate AI into teaching practices and teachers' perspectives on their educational uses of AI (Iyamuremye et al., 2024; Erümit & Özdemir Sarıalioğlu, 2025). This study fills the gap in the literature as it contributes with a deeper analysis of the views, concerns, expectations and experiences of the pre-service and in-service chemistry teachers of Turkey regarding AI-based technologies.

Such information could help teachers, teacher educators, researchers and other education stakeholders make better decisions about the adoption of AI technologies in chemistry education as they become more prevalent in the educational sphere.

Also, recent studies point out that the success of AI adoption depends, among others, on effective communication about its purposes, benefits and limitations (Chounta et al., 2022). Thus, these results can serve as a basis for further mixed and quantitative methods studies on AI integration, teacher professionalisation and technology-enhanced teaching and learning in the chemistry discipline and other fields of education.

1.3 Definitions of key terms

Artificial Intelligence: In this study, artificial intelligence (AI) refers to computer systems that can support teaching and learning processes in chemistry education by

carrying out tasks that typically require human intelligence, such as learning, reasoning, problem solving, and decision making (Miao et al., 2021).

AI-Based Tools: The term will be used in this study to describe artificial intelligence applications that are intended to support teaching and learning by helping with instructional tasks like content creation, lesson planning, assessment, feedback, and personalised learning in chemistry education (Holmes et al., 2019).

Perception: This study refers to "perception" as the way in which chemistry instructors interpret and assess AI-based resources in the context of teaching chemistry (Robbins & Judge, 2023).

Teachers' Experience of AI: In this research, experience as a term will refer to chemistry teachers' practical interactions with AI-based tools and the knowledge, understandings and reflections developed through their use in educational practice (Sung & An, 2026).

Chemistry Education: It will be defined as the teaching and learning of chemistry through evidence-based instructional methods with the goal of enhancing students' conceptual understanding and learning outcomes (Cooper & Stowe, 2018).

Pre-service Chemistry Teachers: In this study, the teachers of university students who are involved in the chemistry teacher education programs and preparing to be teachers are named as pre-service chemistry teachers (Darling-Hammond et al., 2017).

In-service Chemistry Teachers: In this study, the term refers to chemistry instructors who teach chemistry at the high school level (Darling-Hammond et al., 2017).

CHAPTER 2

LITERATURE REVIEW

In the fast globalizing world, Artificial Intelligence (AI) has become a driving force in a variety of sectors, including education. With the increasing integration of AI-based tools into classrooms, it has become essential for researchers to investigate the ways in which teachers view, experience, and adapt to these technologies. This chapter examines the current body of literature regarding the incorporation of AI into educational settings, with a particular focus on its applicability to the field of chemistry education. The purpose of the review is to establish a theoretical and empirical framework for investigating the perceptions and experiences of Turkish pre-service and in-service chemistry teachers pertaining to the integration of AI-based tools into their teaching practices. To achieve this objective, the chapter is organized into seven sections based on literature knowledge accumulation: (1) the definition and conceptual background of AI, (2) the implementation of AI in education, (3) usages of AI in chemistry education, (4) teacher perspectives on AI's use in education, (5) teachers' experiences with AI tools, (6) the risks and constraints of AI integration in classrooms, and (7) ethical concerns relating to the use of AI in education.

2.1 The definition and conceptual background of AI

The term AI was first used by McCarthy in 1956. Over the years, AI has been researched and described by many researchers. For instance, McCarthy defined artificial intelligence as constructing intelligent machines, particularly intelligent computer programs, using science and engineering approaches (McCarthy, 2007).

Similarly, AI is defined by Haenlein and Kaplan (2019) as the capacity of a system to accurately understand outside input, learn from it, and apply that knowledge to accomplish particular objectives and tasks through adaptable change. These definitions highlight the process-oriented perspective of artificial intelligence, which focuses on building intelligent systems with the capacity to learn and adapt.

On the other hand, Russell and Norvig (2010) defined artificial intelligence as the development of agents that perceive their environment, reason about it, and take suitable actions to achieve objectives. This definition is one of the most widely accepted and contemporary. Their methodology emphasizes AI's ability to replicate human cognitive capabilities, including learning, problem-solving, and decision-making, in intricate environments. In contrast to the previous definitions, this perspective emphasizes the behavioral functions of AI systems and their capacity to operate independently and adaptively.

The definitions above agree that AI is the process of designing and implementing systems that imitate aspects of human intelligence, despite their varying emphases. AI is essentially a multidisciplinary effort to construct machines that may carry out intelligent tasks independently, regardless of whether one views it through a perspective of engineering or functionality.

2.1.1 Artificial Intelligence Types

Artificial Intelligence (AI) is a broad category of technologies and applications that are designed to replicate or enhance human cognitive capabilities (Almasri, 2024). It is imperative to investigate the fundamental technologies and key categories of AI to gain a more comprehensive understanding of how it can be applied in educational environments, particularly in the context of chemistry instruction.

Artificial Narrow Intelligence (ANI) denotes AI systems constructed to do certain, predetermined tasks with exceptional precision, frequently exceeding human abilities within that restricted domain (Latif et al., 2023). These systems are designed for specific functions, like language translation, pattern recognition, and adaptive

learning aids utilized in digital education (Almasri, 2024). Kuusi and Heinonen (2022) assert that ANI functions within limited contexts and is devoid of the general reasoning capabilities inherent to human cognition. In the classroom, ANI technologies can deliver tailored feedback, streamline administrative duties, and customize instruction, rendering them particularly relevant for contemporary educational practices. Latif et al. (2023) additionally observe that ANI's implementation in diverse learning management systems illustrates its capacity to enhance efficiency and learner engagement without requiring human-like adaptability.

Conversely, Artificial General Intelligence (AGI) embodies a more ambitious objective: the creation of AI systems proficient in executing any cognitive task achievable by a person. AGI would demonstrate the ability to reason, learn, solve problems, and adapt across various domains without restriction to predetermined tasks (Latif et al., 2023). Kuusi and Heinonen (2022) contend that the potential of AGI resides in its capacity to address unprecedented problems using generalizable knowledge, so establishing it as a transformational influence on the future of education. Nonetheless, the same authors emphasize the conjectural aspect of AGI, noting that such systems are still theoretical and not yet realized. From an educational perspective, AGI has the potential to transform teaching by acting as a diverse pedagogical agentable to assess student requirements, modify instructional approaches in real time, and offer socio-emotional assistance. However, the absence of current AGI systems constrains its practical implementation at this time.

The third category, Artificial Superintelligence (ASI), denotes a theoretical type of AI that exceeds human intelligence across all quantifiable dimensions, encompassing creativity, decision-making, emotional intellect, and ethical reasoning (Brundage, 2015). ASI signifies not only technological progress but also a significant epistemological advancement that could provide both existential threats and opportunities (Brundage, 2015). Latif et al. (2023) assert that ASI presents intricate ethical dilemmas about autonomy, control, and value alignment, especially in human-centered fields such as education. Although ASI may eventually function

as a meta-tutor or curriculum designer that surpasses human specialists, its speculative characteristics and inherent dangers make it mainly unsuitable for current educational planning.

From a comparison perspective, ANI, AGI, and ASI represent escalating degrees of autonomy and generality. ANI systems are reactive and specialized; AGI systems are proactive and versatile; and ASI systems would be self-enhancing and potentially autonomous beyond human oversight. This hierarchical model represents a continuum of cognitive and functional abilities (Kuusi & Heinonen, 2022). Although AGI and ASI are still theoretical, ANI's prevalence in contemporary educational applications renders it the most relevant category for examining the incorporation of AI into education at present (Almasri, 2024).

Moreover, authors' viewpoints differ regarding the urgency of integrating each sort of AI into educational practices. Kuusi and Heinonen (2022) maintain a cautious yet hopeful perspective, proposing that although AGI and ASI possess transformative potential, educational policy and practice should presently prioritize the ethical implementation and pedagogical coherence of ANI systems. Latif et al. (2023) assert that prioritizing ethical control of limited AI systems is essential to avert problems like algorithmic prejudice, data privacy infringements, and educational disparities.

This study investigates the experiences and perspectives of Turkish pre-service and in-service chemistry teachers concerning AI-based tools, demonstrating that the technologies analyzed distinctly align with the domain of Artificial Narrow Intelligence (ANI). Kuusi and Heinonen (2022) contend that ANI systems are presently the most relevant type of AI in education, due to their proficiency in executing narrowly specified activities such as pattern recognition and data processing with high accuracy, while lacking general reasoning abilities. Similarly, Latif et al. (2023) highlight that ANI is currently included in actual educational platforms, enabling functions such as student evaluation, customized training, and adaptive feedback systems. These technologies encompass AI-based assessment platforms, customized learning dashboards, and intelligent tutoring systems resources extensively utilized in educational environments worldwide and

progressively embraced in disciplines such as chemistry education (Holmes et al., 2019; Zawacki-Richter et al., 2019).

Considering that AGI and ASI are still theoretical constructs not yet actualized, their significance to empirical investigations is negligible. Kuusi and Heinonen (2022) warn that while AGI could eventually revolutionize education with its adaptable capabilities, current educational policy and practice must focus on the ethical implementation of existing ANI systems. Latif et al. (2023) advocate for urgent focus on the governance of narrow AI technologies, namely addressing algorithmic bias, transparency, and educational equity. Consequently, examining how educators perceive, adapt to, and ethically interact with ANI-based tools is both contemporary and crucial, particularly in STEM fields such as chemistry, where these tools are more prevalent.

2.1.2 Fundamental Artificial Intelligence Technologies

Artificial intelligence technologies encompass a range of computational techniques that mimic human cognitive processes, such as language use, perception, reasoning, and learning (Almasri, 2024). Among the AI tools most relevant in the current study are Generative AI, Natural Language Processing (NLP), Computer Vision (CV) and Machine Learning (ML). The rapid growth of generative AI has led to increasing discussions and applications for these technologies in educational research (Yang et al., 2025). Understanding these technologies is essential for mapping their pedagogical affordances and identifying how pre-service and in-service teachers use them in actual classroom settings.

Machine learning (MI) is a key part of AI (artificial intelligence). What makes it different is that systems can improve their performance with data input without having to be programmed explicitly. In education, ML-based apps are used to predict how well students will do, find out what they need to learn, and change how they get feedback. In the realm of chemistry education, machine learning can enhance formative assessment technologies that modify questions according to student replies

or provide educators with predicted insights into student misconceptions (Zawacki-Richter et al., 2019). Chen et al. (2024) further demonstrate how ML-driven platforms assist chemistry educators by automatically classifying student errors and suggesting tailored learning pathways.

Natural Language Processing (NLP) is a branch of artificial intelligence which provides computers to comprehend, interpret, and generate human language (Treviso et al., 2023).

Computer vision (CV) is the ability of AI systems to understand and analyze visual data, such as photos and videos. In schools, CV has been used to check handwriting in real time, analyze lab experiments, and keep an eye on student behavior. CV can automatically look over chemistry class experiments done by students and give them timely comments on their technique or correctness in the lab (Zawacki-Richter et al., 2019). Computer Vision holds great promise for educational use, but it remains challenging to deploy in the classroom because of hardware needs, computational requirements, and the difficulty of customising models to different learning contexts (Guo et al., 2024; Jiang & Fu, 2024).

Generative AI is the term used to describe AI that can generate new content. This can be anything from text, images, questions, simulations, explanations, or other instructional content. The most common uses of generative AI in education are large language models and AI image-generation tools (Dwivedi et al., 2023). Generative artificial intelligence can assist teaching in chemistry education by generating instructional explanations, visual representations, problem sets, and learning materials that allow teachers to present chemical concepts in different ways and aid lesson preparation (Feldman-Maggor et al., 2025; Iyamuremye et al., 2024). However, teachers should check the truthfulness, appropriateness, and pedagogical suitability of AI-generated material before incorporating them in practice. This is to avoid the danger of misinformation and unsuitable instructional decisions (Blonder & Feldman-Maggor, 2024).

Those artificial intelligence (AI) tools may have different purposes but they are increasingly part of all-encompassing education systems. For instance, an AI-infused chemistry learning environment might employ generative AI to generate instructional materials, natural language processing to enable conversational interaction, computer vision to interpret laboratory activities or learner behaviour, and machine learning to analyse student performance data and offer personalised support (Guo et al., 2024). This convergence of artificial intelligence (AI) tools underscores the increasing importance of AI literacy among educators, particularly those instructing complex scientific subjects such as chemistry (Yang et al., 2025).

This study examines the experiences of Turkish pre-service and in-service chemistry teachers with AI tools, revealing that these fundamental technologies underpin most AI-based applications currently in use, such as virtual laboratory simulations, automated feedback systems, and adaptive assessments. Furthermore, understanding the pros and cons of each technology enables teachers to critically evaluate AI systems, promote ethical usage, and tailor AI-based education to meet diverse student needs.

2.1.3 The History of Artificial Intelligence and Its Applications in Chemistry Education

There have been many waves of progress in the field of artificial intelligence (AI). The original aim of machines that employ symbols to replicate intelligent behavior was established by mid-20th century advancements in automated reasoning and symbolic AI (Russell & Norvig, 2010; Turing, 1950). By the 1980s and 1990s, hand-crafted knowledge had become too limited, so academics had to employ data-driven methods. Statistical machine learning, and later deep learning, changed the way we think about language, vision, and planning perception and prediction. In the 2010s, improvements in representation learning and large-scale optimization led to the development of large language models (LLMs) and generative AI, which can create fluent text, code, and media (Fan, 2023). Every new wave of technology brought

with it new tools, such rule-based tutors, predictive analytics, and generative copilots that can talk to people in natural language and provide them individualized knowledge when they need it. These innovations are very important for education.

Education has progressed alongside other industries, yet generally trailing behind them (Guo et al., 2024). In the past, computer-assisted training and intelligent tutoring systems (ITS) used symbolic models to help students learn and give them feedback step by step (Koedinger et al., 2013; Woolf, 2009). Educational data mining and learning analytics with more digital traces (Zawacki-Richter et al., 2019) makes it possible to have early warning systems and flexible routes on a large scale. Deep learning, voice and vision, and LLMs have most recently improved research in AI in Education (AIED); the field now encompasses automated scoring, recommender systems, conversational assistants, and analytics for classroom usage (Guo et al., 2024). A thorough bibliometric study of 6,843 papers shows that STEM (including chemistry) and language learning are the most active subjects. Machine learning, deep learning, computer vision, and speech recognition are the most common technologies in the literature (Guo et al., 2024).

The technology is directly relevant to the teaching of chemistry as the use of artificial intelligence (AI) tools are becoming widely introduced into the teaching process and into teaching and assessment practice (Holmes et al., 2019; Zawacki-Richter et al., 2019). Chatbots can not only clarify on any issues on scientific topics through natural language processing (NLP), but they can also solve any student problems including generating instructional lab protocols. Systems with a function of generating artificial intelligence can automatically generate example problems, text (molecular models), reaction mechanism (multiple-representations explanation) representations and easy-risk laboratory virtual practices which are efficient educational means of studying of chemistry (Yuriev et al., 2025).

Computer vision (CV) systems can be also applied to analyse data obtained from laboratory photos and instructional videos on how to conduct laboratory experiments, for automatic execution of laboratory experimental tasks and processing visual information obtained from lab practice (Kosenkov & Kosenkov,

2021). The computer modelling can predict students' successes and identify their learning barriers and misconceptions (Zawacki-Richter et al., 2019). Recent studies show that K–12 teachers are already using these skills to tailor materials and give timely feedback (Almuhanna, 2025). These studies also raise concerns about AI literacy, egalitarianism, and dependability. In short, the same changes that have profoundly changed AI are also affecting how chemistry concepts are taught, practiced, and tested.

Following the development of AI helps explain why today's tools feel different: Legacy ITS, Intelligent Tutoring System, could not support open-ended discussion, just-in-time generation, and quick adaptation (Fan, 2023; Guo et al., 2024). LLMs and multimodal models can do all of these things. That transformation alters the unit of analysis in classrooms from pre-written materials to content that is created on the run and tailored to the needs of the learners. This is exactly what chemistry teachers and teacher candidates are asking for more and more (for example, error-specific hints, different explanations, and different practice). The evidence continually warns that effective impact relies on pedagogy, teacher ability, and governance (Almuhanna, 2025; Zawacki-Richter et al., 2019). In this research, this context helps to explain why teachers' points of view and which AI features are most important for chemistry are examined.

There are five main groups of modern use cases that fit well with chemistry teaching: i) personalized tutoring and feedback like step-level hints and prompts that target misconceptions, ii) assessment and analytics such as automated scoring of short answers and lab reflections; early-risk flags, iii) content generation/adaptation including problem variants, visuals, rubrics, and simulations, iv) multimodal supports like speech for accessibility and vision for lab/video analysis, and v) teacher workflow which includes lesson planning, differentiation, and formative check-in (Almuhanna, 2025; Guo et al., 2024).

2.2 The implementation of AI in education

The use of artificial intelligence (AI) in schools is becoming a more and more important topic in both educational research and policy debates. AI in education (AIED) is the use of computer systems that can do things like recognize patterns, analyze data, and make decisions to help with teaching and learning. AI-based tools are not meant to replace teachers; instead, they are meant to improve teaching by making it more personalized, efficient, and based on data (Zawacki-Richter et al., 2019).

AI-enabled systems can also analyse huge amounts of learning data from how well a student performs to their learning behaviours and interactions to generate customised feedback and individualised learning paths that are fluid and adaptable to learners' advancement (Khor & K, 2024). Zawacki-Richter et al. (2019) say that these kinds of apps are often utilized in intelligent tutoring systems and learning analytics platforms, where AI is employed to make sure that the material is appropriate for each learner. These adaptive systems seek to better accommodate learner variety than conventional instructional methods by facilitating self-paced and focused learning experiences.

Student assessment and grading have also seen the coming of age of AI. Teachers can use tools such as auto-grading and learning analytics, many of which have AI baked in, to keep up with how each student is performing, to identify where learners may be struggling and to provide more bespoke, data-rich support to improve learning outcomes (Cabral et al., 2025; van Leeuwen et al., 2021). Vincent-Lancrin and van der Vlies (2020) says that AI-assisted assessment methods could help teachers do less paperwork and make formative assessments operate better. The OECD also stresses, though, that these gains depend on how well teachers can understand AI-generated outputs and use them in a meaningful way when making decisions about how to teach.

Contextual and institutional factors have a big effect on how well AI works in schools. The availability of infrastructure, access to digital technologies, and

institutional preparedness are essential in determining the adoption of AI-based applications in educational environments. Furthermore, instructors' digital proficiency and awareness of AI are constantly recognized as essential factors for successful adoption. Without sufficient opportunities for professional growth and support from the school, AI tools might not be used enough or in ways that help students learn (Garzón et al., 2025; Vincent-Lancrin & van der Vlies, 2020).

It is also to discuss the reliability and trustworthiness of using AI in Education. Teachers and researchers are concerned about the 'explainability' of artificial intelligence algorithms, the reliability and validity of findings generated by AI and the risks of bias in algorithms (Gouseti et al., 2025). Garzón et al. (2025), The researchers agreed in their systematic review of 155 empirical research studies in 2020 that the benefits for education from the use of the application were clear but the practicalities of the application of this were challenging including those concerning moral, staff opposition, infrastructure complexity, the inadequacy of Digital Literacy and Digital Dependence. These findings emphasize that the introduction of AI is not merely a technological endeavor but also a pedagogical and organizational one that necessitates meticulous preparation and ongoing assessment.

The literature indicates that the successful integration of AI in education relies on a multifaceted interaction of technological, pedagogical, and human elements (Zawacki-Richter et al., 2019). Teachers are key to how AI-based tools are used in the classroom since their views, skills, and experiences directly affect how these technologies are used in the classroom. Both policy-oriented and research-based studies stress the importance of knowing teachers' views on AI adoption in order to make sure that AI improves the quality and fairness of education (Vincent-Lancrin & van der Vlies, 2020; Zawacki-Richter et al., 2019)

Although the current literature offers significant insights into the integration of artificial intelligence in education, the majority of the research has concentrated on higher education settings, institutional-level adoption, and system-oriented frameworks (Garzón et al., 2025; Vincent-Lancrin & van der Vlies, 2020; Zawacki-Richter et al., 2019). Previous studies have shown that the teachers are often the

mediators of implementation of AI in science but few researchers focus on the experience, perception and training of teachers toward use of AI particularly in science education (Almasri, 2024; Tan et al., 2025). While many scholars have written about the implementation of AI in the education sector, the use and perception of AI-based techniques have been untouched in some fields of study, such as in the chemistry education (Iyamuremye et al., 2024). Hence, there is a need for more empirical studies on teachers' experience and perceptions of AI across specific subjects. In light of these deficiencies, the current study seeks to investigate the perspectives and experiences of Turkish pre-service and in-service chemistry teachers regarding the utilization of AI-based tools in chemistry instruction, thus providing contextually relevant and practitioner-focused evidence to the existing body of literature.

2.3 Usages of AI in chemistry education

Recent studies show that more and more educators are interested in using machine learning (ML) and artificial intelligence (AI) to improve how chemistry is taught and learned. AI is used in many parts of the education to help with lesson preparation and customization, to help students comprehend concepts better, and to make learning in the lab easier (Erümit & Özdemir Sarıalioğlu, 2025; Iyamuremye et al., 2024). Artificial intelligence (AI) is used in chemistry education in many different ways at different levels and in different settings, as shown by both synthesis studies and real-world examples in the classroom (Blonder & Feldman-Maggor, 2024; Erümit & Özdemir Sarıalioğlu, 2025; Iyamuremye et al., 2024; Jiang et al., 2024).

Several review publications provide an overview of the current applications of AI and ML in chemistry teaching. Iyamuremye et al. (2024) performed a critical analysis of research published from 2018 to 2024, identifying the most frequently reported applications in chemistry education as AI-assisted assessment tools, virtual laboratories, adaptive learning platforms, intelligent tutoring systems, and simulations. Erümit and Özdemir Sarıalioğlu (2025) identified simulation-supported

environments and chatbots/conversational agents as prevalent AI-based technologies in scientific and chemistry education within their comprehensive analysis spanning 2014 to 2024. Collectively, these studies demonstrate that AI is often utilized as a supplementary teaching tool rather than being fully included in the curriculum (Erümit & Özdemir Sarıalioğlu, 2025; Iyamuremye et al., 2024).

A common theme in the literature is the use of AI-supported environments in chemistry instruction to help students understand abstract chemical ideas and get around problems with limited access to labs. Virtual labs and simulation-based tools let students interact with molecular representations, reaction processes, and experimental procedures in interactive digital environments. This supports inquiry-based and experiential learning (Erümit & Özdemir Sarıalioğlu, 2025; Iyamuremye et al., 2024). Simultaneously, review findings indicate the utilization of AI for feedback and educational assistance, wherein students gain advantages from guided practice and prompt replies inside structured learning environments (Erümit & Özdemir Sarıalioğlu, 2025; Iyamuremye et al., 2024).

In addition to review evidence, empirical research centered on curriculum provides tangible instances of AI application that correspond with chemistry educational goals. Jiang et al. (2024) introduced an interdisciplinary high school curriculum that combines machine learning with analytical chemistry via a practical problem-solving assignment centered on colorimetric pH analysis. In this implementation, students gathered data, built machine learning models with user-friendly software that doesn't need coding, and used the models to make predictions about chemical measurements. This example shows how AI may be used not just as a tool for learning but also as a way to combine chemistry information with data-driven reasoning skills (Jiang et al., 2024).

AI's role in chemistry education is also discussed in terms of how teachers get ready for lessons and help students in the classroom. Blonder and Feldman-Maggor (2024) examine the application of generative AI in chemistry education, specifically in facilitating the generation of explanations and the creation of instructional resources. When considered solely as "usage," this underscores an alternative avenue for AI

integration: AI technologies can serve as teacher-oriented supports by facilitating lesson preparation procedures and offering educational scaffolds (Blonder & Feldman-Maggor, 2024). This teacher-centered application of the technology builds upon prior literature that has largely framed AI as a student support technology in the form of intelligent tutoring systems, adaptive learning platforms, chatbots, virtual laboratories, and customised educational experiences (Blonder & Feldman-Maggor, 2024; Erümit & Özdemir Sarıalioğlu, 2025; Iyamuremye et al., 2024).

The literature indicates converging themes regarding the application of AI in chemistry education such as personalized support, visualization of chemical phenomena, laboratory-related learning assistance, and data-driven problem solving while also reflecting variations by educational level and implementation contexts. Review studies have repeatedly shown that applications of AI in education are heavily explored in high education and technology-enabled environments and less applications have been presented for secondary education. While some case of secondary school applications has provided extensive examples as of for example curriculum case from Jiang et al. (2024) the movement towards higher education continues to be stressed for recent reviews (Erümit & Özdemir Sarıalioğlu, 2025; Iyamuremye et al., 2024; Zawacki-Richter et al., 2019). Furthermore, a substantial portion of the current literature is focused on tools and outcomes, with comparatively limited understanding of how chemistry educators choose, interpret, and implement these tools in their daily instruction (Blonder & Feldman-Maggor, 2024; Erümit & Özdemir Sarıalioğlu, 2025; Iyamuremye et al., 2024).

In response to this gap, the current study enhances the literature by redirecting the emphasis from AI tools to the opinions of chemistry teachers regarding their utilization. This study investigates the perspectives and experiences of Turkish pre-service and in-service chemistry teachers concerning AI-based tools in chemistry education. It enhances the existing usage-oriented evidence base by providing practitioner-centered insights into the implementation of AI applications in actual classroom settings and professional practices (Blonder & Feldman-Maggor, 2024; Erümit & Özdemir Sarıalioğlu, 2025; Iyamuremye et al., 2024; Jiang et al., 2024).

2.4 Teacher perspectives on AI's use in education

2.4.1 Teachers' Perceptions and Acceptance of Artificial Intelligence in Education

Research on educators' perspectives on the implementation of artificial intelligence (AI) in education has been previously conducted focusing on teacher's attitudes, perception, perceived usefulness, acceptance and readiness of implementation (Tan et al., 2025). The literature review revealed studies that examined in-service teacher in Türkiye showed positive teacher's perception towards AI as an aid in improving their teaching and minimising their burden (Çayak, 2024). Çayak (2024) also found that teachers with higher AI literacy tend to have more positive perceptions of AI in their teaching compared to teachers with lower AI literacy.

In a similar study, Uygun (2024) looked into how teachers felt about AI and discovered that many of them thought it could help make lessons more effective and complement their teaching methods. Nonetheless, the same survey also recorded apprehensions regarding teachers' insufficient preparation and ambiguity concerning the integration of AI into classroom learning. These results indicate that educators' viewpoints are influenced by both the perceived advantages and disadvantages of AI implementation (Uygun, 2024).

Studies based on technology acceptance frameworks elucidate additional aspects that shape instructors' perceptions. Erümit and Özdemir Sarıalioğlu (2025), in their systematic study of AI in science and chemistry education, indicated that perceived usefulness and perceived simplicity of use are commonly identified as factors influencing teachers' acceptance of AI-based technologies. The authors observed that educators are more likely to articulate favorable perspectives when AI applications are congruent with pedagogical objectives and instructional requirements, rather than being presented as externally mandated technologies.

Policy-oriented literature also talks about how teachers feel about AI use by stressing the significance of trust, accountability, and human oversight. According to Miao and Holmes (2023) teachers are less likely to use generative AI in the classroom because they worry about how reliable AI-generated outputs are, whether they might be biased, and how important it is for them to be responsible when evaluating AI-supported instructional materials (Miao & Holmes, 2023). This guidance puts teachers in charge of making important decisions about whether and how AI is used in schools.

While these studies elucidate teachers' general views about AI utilization, the majority of the literature treats instructors as a monolithic entity, failing to distinguish opinions by subject area. As a result, this corpus of research does not thoroughly investigate discipline-specific aspects that may affect instructors' perspectives, such as the characteristics of topic or instructional methodologies.

2.4.2 Pre-Service and In-Service Teachers' Perceptions of AI Usage

Several research studies clearly differentiate between the viewpoints of pre-service and in-service instructors regarding the utilization of AI in education. The researches related to this field show that pre-service teachers' attitudes towards AI based tools are mostly positive. However, these attitudes have been affected by many factors such as their knowledge levels of Artificial intelligence, the perceived readiness levels of the individuals regarding the usage of these technologies and the available training opportunities regarding Artificial Intelligence (Mustafaoğlu & Alkan, 2025). Moreover, Pre-service science teachers considered that ChatGPT was useful for science education instruction the scheduling of science lesson, teaching methods, students-personalized learning for students to understand science lesson (Lee & Zhai, 2024). In the similar study, Ishmuradova et al. (2025) found that pre-service teachers were similarly worried about how AI will be used in the classroom, especially when it came to checking the accuracy of AI-generated content and using

AI ethically. These results show that pre-service teachers have both good views and doubts about how to use what they've learned in real life.

Research concentrating on in-service teachers reveals an alternative trend. Çayak (2024) stated that the views of in-service teachers on AI were intimately linked to their professional experience and the realities of the classroom. Teachers in this study assessed AI technologies according to their alignment with current curricula, evaluation methods, and temporal limitations. In a similar vein, Uygun (2024) found teachers' views that AI is a tool that may promote teaching and learning in terms of offering chances for personalised education, efficient feedback and meaningful teaching. On the other hand, they were also concerned about privacy and ethical issues, lack of professional support and the clear direction of their institutions.

Likewise, a study on EFL education by Tümen Akyıldız (2026) identified that the variances in pre-service and in-service teachers' views regarding AI were associated with career phase, previous experience in teaching, and AI proficiency. Meanwhile, Erümit and Özdemir Sarıalioğlu (2025) explained that, due to these efforts to establish AI literacy and pedagogical abilities of prospective teachers in service programs, research in this area currently remains concentrated pertaining to the population of prospective teachers; and also, in spite of very few works with those teachers and in the school educational environments.

In short, according to the literature on teachers' perspectives toward AI use in education documents a range of attitudes shaped by perceived usefulness, technological competence, and contextual constraints. Studies conducted with in-service teachers report generally positive attitudes toward AI, accompanied by concerns related to training and implementation (Çayak, 2024; Uygun, 2024).

2.4.3 Chemistry Teachers' and Pre-Service Chemistry Teachers' Perceptions on AI Use

Studies on chemistry education reveal that educators' views on AI are shaped by the discipline's distinctive attributes. Chemistry teaching includes abstract

submicroscopic ideas, different ways to show them, and hands-on work in the lab. These things affect how teachers judge the effectiveness of AI-based technologies. Erümit and Özdemir Sarıalioğlu (2025) found that studies on chemistry often link AI use to teaching tools, including simulations, virtual labs, and support for testing and problem-solving.

Erümit and Özdemir Sarıalioğlu (2025) provided instances in which chemistry educators and students utilized generative AI systems, such as ChatGPT, for solving chemistry problems, composing laboratory reports, and creating assessment materials. These examples show how AI is talked about in the literature as a possible way to help with chemistry education and learning.

At the same time, chemistry teachers' views are influenced by worries about how accurate and trustworthy AI-generated content is. Blonder and Feldman-Maggor (2024) stressed that AI-generated explanations in chemistry could have conceptual errors or misleading representations, therefore teachers need to use their subject knowledge and teaching experience while utilizing these tools. The authors emphasized that teachers' chemistry knowledge and pedagogical content knowledge are essential for assessing the suitability of AI outputs for instructional purposes.

There is similar evidence for the generally positive attitude of pre-service chemistry and science teachers towards AI tools, even though is also evidence that these teachers express the need to use AI technologies with a sense of criticality and ethics (Harianti et al., 2025; Mustafaoğlu & Alkan, 2025). Powell and Courchesne (2024) propose that generative AI could support lesson planning by assisting teachers in developing instructional materials and structuring lesson plans. But they caution teachers that AI-generated material may need to be vetted for accuracy and relevance to curriculum goals before being used in lessons with students. In general, there aren't many studies that look at what chemistry teachers think about AI. A significant portion of existing research either addresses scientific education in a general context or analyzes AI tools without prioritizing instructors' disciplinary assessments. As a result, empirical evidence contrasting the perspectives of pre-service and in-service

chemistry teachers within the same educational context is notably limited (Blonder & Feldman-Maggor, 2024; Erümit & Özdemir Sarıalioğlu, 2025).

Within chemistry education, existing studies highlight that teachers' perspectives on AI are closely connected to chemistry-specific instructional demands, including laboratory-based learning, visualization of abstract concepts, and assessment practices (Erümit & Özdemir Sarıalioğlu, 2025). However, the literature also indicates that research focusing specifically on chemistry teachers' perspectives particularly studies examining both pre-service and in-service teachers together is limited.

2.5 Teachers' experiences with AI tools

In the past few years, there has been more empirical research on teachers' experiences using artificial intelligence (AI) tools. Several studies have looked at how teachers use AI directly in the classroom, during preparation, and during assessments. Current research examines educators' experiences with generative AI tools like ChatGPT, along with AI-enhanced platforms utilized for lesson planning, content creation, feedback delivery, and administrative responsibilities in various educational contexts (Alé et al., 2025; Gamlem et al., 2026; Tripathi et al., 2025; Van den Berg, 2025; Wulandari & Purnamaningwulan, 2024). These studies concentrate on teacher's documented behaviors and lived experiences rather than solely on attitudes, offering empirical evidence of the utilization of AI tools in routine educational activities.

In a recently published body of research conducted on pre-service chemistry teachers' experience with AI tools in the context of teacher preparation programs, teachers consistently use AI for information retrieval, material development and instructional design of lessons while holding positive attitudes about their usage and reflecting the ethical consideration of their use (Harianti et al., 2025). Similarly, Akaygun and Kılıç (2025) concluded pre-service chemistry teachers used generative AI in chemistry context to develop chemical visualisations that integrate

macroscopic, symbolic and particulate representation, highlighting AI's applicability to design learning materials and convey chemistry knowledge. The teachers also agreed that the results of the AI need to be critically interpreted and reviewed due to the possibilities of producing errors and inconsistencies in the created visual forms. Consistent with this observation, Aydın Gunbatar et al. (2025) studied the teacher preparation program participants with various years of experience in AI supported lesson planning. They found that different experiences lead participants with higher teaching experience to actively review and edit AI produced plans while those with lower teaching experience depend more on AI in planning activities. Recent research shows that pre-service chemistry teachers mainly use AI in search for information, lesson preparation, instructional material development and writing of chemistry teaching materials (Akaygun & Kılıç, 2025; Harianti et al., 2025). As the participants' experiences at different teaching levels indicate, the main differences are not necessarily in the intention of using AI but more in how teachers manage AI outcomes, where more experienced teachers tended to modify, revise and critically verify the AI-derived information to integrate it to their instructional purposes, whereas less experienced teachers leaned on the direct use of AI in preparing for the lesson (Aydın Gunbatar et al., 2025).

Evidence from systematic reviews suggests that educators seem to be using AI to support instructional planning, improve task efficiency, and assist with professional learning and administrative tasks (Garzón et al., 2025). Wulandari and Purnamaningwulan (2024) conducted a qualitative case study with Indonesian pre-service English teachers during their teaching practice, documenting the participants' experiences with tools including ChatGPT, Copilot, and Quizizz AI. The pre-service teachers indicated that AI tools facilitated ideation, material preparation, and the creation of tailored learning resources, especially when faced with the time limitations imposed by practical obligations. These experiences were predicated on continuous classroom utilization over a six-week duration, during which participants included AI tools into lesson design and assessment-related activities.

Similar trends are observed in higher education and teacher training settings. Gamlem et al. (2026) conducted a mixed-methods study with Norwegian pre-service teachers, revealing that the majority of participants possessed firsthand experience with generative AI tools, especially for lesson preparation, content discovery, and feedback-related activities. Survey and interview data revealed that participants actively engaged with AI technologies during their teacher education programs, emphasizing practical usage over theoretical applications. There were differences between new and more experienced users, and the experiences they reported were different based on how much they had used AI tools before and how confident they were in utilizing them (Gamlem et al., 2026).

Research studies concentrating on in-service educators similarly record experiential interaction with AI in educational environments. Alé et al. (2025) conducted a large-scale quantitative study in Chile to investigate teachers' reported experiences using AI as an educational tool, utilizing an adapted Intelligent TPACK framework. Teachers said they used AI technologies to plan lessons, prepare tests, and help with teaching. Their experiences, however, differed across topic areas and teaching levels, indicating that the utilization of AI was influenced by contextual and disciplinary aspects. The report presents empirical evidence regarding teachers' experiences with AI integration in primary and secondary school settings.

A qualitative study carried out in K–12 environments clarifies the experiences of instructors regarding AI integration in their regular instructional practices. Tripathi et al. (2025) examined educators' experiences with AI at private schools in India via semi-structured interviews. Teachers talked about how they used AI technologies to organize lessons, make teaching materials, and help explain things in class. At the same time, participants said they had to adapt their professional duties as AI tools became part of their daily routines. These experiences were conceptualized as continuous processes rather than discrete occurrences of technology utilization (Tripathi et al., 2025).

Subject-specific research offers more understanding of teachers' experiences with AI integration. In this study, Park et al. (2023) studied how three science teachers in

secondary schools in Singapore used an AI-integrated science lesson package to introduce the use of machine learning topics in their science classes. The lessons asked teachers to introduce students to AI through activities including predictive modelling through the Orange software and explicitly relate AI principles to scientific modelling practice. While the teachers saw the lesson package as useful for bringing AI to science classes, they described a range of challenges: including low self-efficacy in their AI knowledge, the difficulty of linking AI and science conceptually, worry over making it fit into the school's curriculum and questions about whether it was a fit for different types of learners. Their experiences originated from the implementation of AI-integrated teaching into established science curricula, emphasizing the influence of disciplinary context on AI utilization.

Studies in open and distance learning environments also record teachers' practical involvement with AI tools. Van den Berg (2025) examined educators' experiences with AI in an open distance learning context in South Africa. Participants indicated the utilization of AI tools, notably ChatGPT, for lesson planning, content dissemination, tutoring, and administrative responsibilities like preparing and feedback to reports, boosting written communications, curriculum forms, policy documentation, and more. Participants said that these experiences saved them time and helped them with their teaching, although the level of adoption differed based on how comfortable and knowledgeable they were with AI tools.

Previous research studies demonstrated that pre-service and in-service teachers utilised AI tools to plan lessons and develop teaching materials through identifying teaching objectives, designing presentations, learning activities, worksheets, and teaching resources. In-service teachers also reported that they used AI tools for instructional activities like giving individual tutoring and immediate responses to a single question, and assessment activities such as creating quizzes, question papers and various types of questions for each of the cognitive levels. The use of AI in administrative and professional work also includes the writing of reports, progress reports, formal documents, letters of recommendation, curriculum framework templates, explanation of policy statements and translation of work (Gamlem et al.,

2026; Tripathi et al., 2025; Van den Berg, 2025). Nonetheless, most of these studies investigate teachers' experiences within general education, language education, or expansive STEM contexts, with minimal emphasis on chemistry as a specific subject area (Park et al., 2023; Van den Berg, 2025). Moreover, there is a lack of studies that evaluate the experiences of pre-service and in-service teachers within the same disciplinary and national framework. This study builds on previous research by investigating the experiences of Turkish pre-service and in-service chemistry teachers utilizing AI-based tools in chemical education.

2.6 The risks and constraints of AI integration in classrooms

While research indicates that educators have utilized AI tools for many instructional and professional activities, the literature uniformly highlights numerous dangers and limitations that hinder successful classroom integration (Miao & Holmes, 2023; Vincent-Lancrin & van der Vlies, 2020). Research syntheses and policy-oriented studies categorize these limits as technological, pedagogical, and institutional, highlighting that the integration of AI in classrooms is influenced not just by the availability of tools but also by contextual and systemic factors (Zawacki-Richter et al., 2019).

A prevalent problem documented in the literature relates to the dependability and accuracy of outputs created by artificial intelligence. Research and policy documents indicate that generative AI systems can generate responses that seem credible but are factually incorrect or deceptive, creating difficulties for classroom implementation (Miao & Holmes, 2023; Vincent-Lancrin & van der Vlies, 2020). This issue is especially important when talking about how to teach, because teachers have to check AI-generated content before using it in class, which brings another level of responsibility and work to their jobs (Miao & Holmes, 2023).

Along with worries about accuracy, the literature talks about problems with AI systems' transparency and explainability. OECD studies show that AI outputs that are hard to explain can make it hard for teachers to grasp how they are made. This can make it hard for teachers to make informed decisions about how to educate and trust AI-supported technologies (Vincent-Lancrin & van der Vlies, 2020). Zawacki-Richter et al. (2019) similarly observe that several research studies about AI in education concentrate on applications and outcomes, while providing insufficient discourse on implementation issues, hence hindering educators' capacity to critically assess AI utilization in classroom settings.

There is a lot of information about pedagogical and professional limits. Miao and Holmes (2023) guidance stresses that instructors frequently lack adequate training to critically assess AI outputs, incorporate AI tools into lesson planning, and ensure that AI usage aligns with curricular objectives, recognizing teacher capacity as a significant barrier to classroom integration. Several research studies indicate that responsible AI utilization may augment teachers' workload, necessitating additional time for monitoring student engagement, evaluating AI-generated materials, and modifying teaching tactics accordingly (Miao & Holmes, 2023; Zawacki-Richter et al., 2019).

Additionally, the literature underscores difficulties associated with curriculum alignment and subject-specific integration. In a discipline-based implementation study, Park et al. (2023) reported that science teachers encountered challenges in integrating AI into their existing science lessons, mainly because of their low confidence in AI content knowledge and difficulties in incorporating AI content while keeping the existing curriculum priorities. While numerous research studies do not explicitly categorize limitations by subject area, they suggest that integration requirements may differ based on the epistemic and pedagogical attributes of the discipline (Park et al., 2023; Zawacki-Richter et al., 2019).

Institutional and policy-related limitations are also prevalent themes in the literature. UNESCO and OECD publications underscore that the lack of explicit institutional

directives, governance structures, and school-level rules may impede teachers' utilization of AI technologies in the classroom (Miao & Holmes, 2023; Vincent-Lancrin & van der Vlies, 2020). Studies indicate that educators frequently function without official directives regarding permissible AI utilization, data safeguarding, or evaluative methodologies, hence hindering uniform and assured application within educational environments (Miao & Holmes, 2023).

Equity and access difficulties are often recognized as constraining factors. OECD studies show that not everyone has the same access to digital infrastructure, AI tools, and technical support. This could affect how AI is used in schools and classrooms, making it harder to integrate it in resource-constrained settings (Vincent-Lancrin & van der Vlies, 2020). These discrepancies are identified as structural limits that transcend the influence of individual teachers, highlighting the significance of system-level circumstances in determining classroom AI utilization (Vincent-Lancrin & van der Vlies, 2020).

The literature collectively suggests that the risks and limitations linked to AI integration in educational settings are multifaceted and contingent upon context, including aspects of technical reliability, teacher proficiency, curriculum coherence, institutional governance, and equity considerations (Miao & Holmes, 2023; Vincent-Lancrin & van der Vlies, 2020; Zawacki-Richter et al., 2019). A significant portion of this literature discusses restrictions at a broad classroom level rather than within individual topic areas. However, discipline-specific studies indicate that subject settings influence these constraints during classroom implementation (Park et al., 2023). Zawacki-Richter et al. (2019) assert that there is insufficient critical reflection on pedagogical obstacles and risks associated with AI utilization from an educational standpoint. Miao and Holmes (2023) also points out problems with policy, institutional readiness, and teacher ability to deal with AI-related threats in schools.

This study focuses on pre-service and in-service chemistry teachers in Türkiye to give context-specific evidence on experienced hazards and limits, building on these broader issues.

2.7 Ethical concerns relating to the use of AI in education

There are some important questions about the ethical responsibilities for the design and implementation of the technology and the use of this technology in the classroom with the increasing use of artificial intelligence (AI) in teaching and learning processes. While the promise of AI to revolutionise teaching and learning appears to be profound, as it is adopted into more classrooms, more educators are becoming conscious of the ethics of AI use in education (Tang & Su, 2024). Instead, ethical standards are becoming the essential building blocks on which to base ethical uses of AI in education. This means that the development of the moral character of the system should use AI to teach that is fair, accountable and transparent, and that is ultimately good for learners and for their educators (Floridi et al., 2018; Tang & Su, 2024). The literature has raised a wide range of ethical issues with considerable focus on issues relating to privacy, accountability, transparency and academic honesty. A systematic review by Tang and Su (2024) identified the most cited five ethical implications of AI use in the classroom, which are algorithmic bias and discrimination, data privacy leakage, lack of transparency, reduced autonomy, and academic dishonesty. Fairness, privacy, transparency, accountability, autonomy and beneficence have been identified as the most common principles of ethics that should form the basis for the use of AI in the classroom.

Privacy and data protection are one of the most discussed ethical concerns of AI's uses in education (Tang & Su, 2024). The process of AI in learning technologies generating, recording and managing learner data raises questions on how personal data will be accessed, guarded and managed (Tang & Su, 2024). Transparency and accountability issues are closely related to privacy issues as they require transparency of AI operations and human beings to take control of AI decisions in education (Floridi et al., 2018). Adams et al. (2023) also suggested a framework in the classroom where guidelines for AI usage would effectively maintain accountability, transparency, and decision-making processes and help teachers to use AI efficiently.

Another significant ethical concern that arises in the educational use of artificial intelligence is upholding academic honesty and integrity. With the rise of modern generative AI systems capable of producing text-based essays, papers and other educational content, the issue of plagiarism, ownership, authenticity and intellectual property has received significant attention (Al-Zahrani, 2024). Moreover, concerns over adequate citation practices and the manner in which learners should acknowledge AI assistance in their tasks has gained further prominence in the use of AI generated materials, all of which require that AI supports learning without crossing the limits of honesty or misattributing original ownership (Al-Zahrani, 2024). Similar to Al-Zahrani's study, Tang and Su (2024) found academic dishonesty to be a primary reported ethical consequence of AI adoption in the education domain.

However, ethically the usage of AI should be much wider than the mitigation of risks but should consider supporting teachers with making informed and pedagogically sound usages of AI. Thus, Adams et al. (2023) propose the use of a framework that includes key governance principles for AI deployment in schools: AI literacy, pedagogical soundness, teachers' wellbeing and informed decisions. Thus supports the teaching profession through responsible uses of AI. Al-Zahrani (2024) found that AI ethics needs a response based on technology as well as educational components to increase awareness and responsibilities in the teaching profession and promoting them to challenge AI based responses with a view to using this responsibly.

CHAPTER 3

METHODOLOGY

In this chapter, the research questions, design of the study, participants, data collection tool and procedure, data analysis, trustworthiness of the study, ethical considerations, limitations and assumptions of the study were explained, respectively, to facilitate understanding of the research properly.

3.1 Research questions

The purpose of the study was to have an idea about the perceptions and experiences of Turkish Pre-service and in-service chemistry teachers' usage of AI in the classrooms. In light of this study, it aims to answer the following research questions:

What are Turkish pre-service and in-service chemistry teachers' perceptions regarding AI in chemistry education?

What are Turkish pre-service and in-service chemistry teachers' experiences regarding the use of AI in chemistry education?

What are Turkish pre-service and in-service chemistry teachers' recommendations for the effective integration of AI into chemistry education?

What are the similarities and differences between pre-service and in-service chemistry teachers in terms of their perceptions, experiences, and recommendations for the integration of AI-based tools in chemistry education?

3.2 Design of the Study

The present study was designed as a basic qualitative research study in order to explore the perceptions and experiences of Turkish pre-service and in-service

chemistry teachers about the use of AI-based tools in the context of chemistry education. Qualitative research is appropriate to explore how people make sense of their experiences, construct meaning, and understand a particular phenomenon in their social and educational contexts (Merriam & Tisdell, 2016). Moreover, qualitative research also examines how people and groups make sense of their experiences. In this research, researchers try to identify meaningful patterns and themes through interpretation of the data to gain insight into participants' perspectives and experiences (Patton, 2015).Therefore, a qualitative research method was found to be suitable to investigate the perceptions and experiences of pre-service and in-service chemistry teachers on the use of AI-based tools in chemistry education.

A basic qualitative research design was used in the qualitative research approach. According to Merriam and Tisdell (2016), the main purpose of basic qualitative research is to explore how people make sense of their experiences and interpret the world around them. In contrast to phenomenology, which is interested in the essence of lived experiences, and grounded theory, which aims to generate theory, basic qualitative research aims to understand the perspectives of participants on a particular phenomenon. Hence, this design was deemed suitable to explore perceptions and experiences of chemistry teachers and pre-service chemistry teachers in the use of AI-based tools in chemistry education.

Data were collected through semi-structured interviews, which provided the opportunity for the participants to express their views and experiences in depth and for the researcher to ask follow up questions when clarification or elaboration was needed. This flexible structure yielded rich and detailed data on pre-service chemistry teachers' and chemistry teachers' experiences with AI-based tools and perceptions of opportunities, benefits, challenges and applications of these tools in the context of chemistry education.

3.3 Participants

Participants were selected based on purposive sampling, which is a common sampling approach in qualitative research. Purposive sampling is the deliberate choice of participants who are information-rich and therefore able to provide rich insights into the phenomenon of interest (Patton, 2015). Merriam and Tisdell (2016) also stated that qualitative researchers intentionally choose participants that can give information relevant to the study objectives. Therefore, the current study was suitable for purposive sampling because it allows the researcher to purposefully choose participants who can give rich and relevant information about the phenomenon being studied. In this study, the participants were selected separately from pre-service and in-service chemistry teachers according to the characteristics relevant to the purpose of the study. The pre-service chemistry teachers were in the final year of the chemistry teacher education program, taking the teaching practice course and had completed most of their classroom teaching practices in the practicum. These characteristics guaranteed that the participants were sufficiently exposed to real teaching experiences and were able to reflect on the potential use of AI-based tools in chemistry education. The in-service chemistry teachers were currently teaching chemistry at the high school level, and thus had up-to-date professional experiences and practical knowledge of teaching chemistry in real classroom environments. Thus, purposive sampling was considered suitable for the present study since it was focused on understanding the perceptions and experiences of people who are actively involved in teaching chemistry in high schools and can provide knowledgeable insights into the use of AI-based tools in chemistry education.

The study was carried out in Türkiye. A total of 19 participants including nine pre-service chemistry teachers and ten in-service chemistry teachers. Informed consent was obtained from all subjects involved in the study. Participation was voluntarily. To maintain confidentiality and protect the identities of the participants, all

participants were assigned pseudonyms, and these were used when presenting quotations and reporting findings throughout the study.

The first group of participants was nine pre-service chemistry teachers who were taking the Chemistry Teacher Education Program at a university in Ankara. The participants were selected as they were final year students and were undertaking their teaching practicum at the time of data collection. All pre-service teachers had previous experience of classrooms at the time of the interviews, either through university-based teaching activities or school-based practicum placements. These experiences were opportunities to reflect on instructional planning, classroom practices, assessment processes, and the potential to incorporate AI-based tools in the teaching of chemistry. Most of the pre-service teachers had no formal education in artificial intelligence. Three participants reported taking university level coursework in AI. Table 3.1 shows the demographic characteristics of the pre-service chemistry teachers.

Table 3.1 *Demographic Characteristics of Pre-Service Chemistry Teachers*

Pseudonym	Gender	Academic Status	Teaching Practicum	AI-Related Coursework
Elif	Female	Senior	Yes	No
Zeynep	Female	Senior	Yes	No
Ece	Female	Senior	Yes	No
Defne	Female	Senior	Yes	Yes
Merve	Female	Senior	Yes	No
Derya	Female	Senior	Yes	No
Ceren	Female	Senior	Yes	No
Emre	Male	Senior	Yes	Yes
Cihan	Male	Senior	Yes	Yes

The second group was composed of ten in-service chemistry teachers who worked in private colleges in Ankara, Turkey. Participants were recruited through the researcher's professional network, as well as through contacts made with chemistry teachers working at different private schools. The participants came from different professional backgrounds, having taught for three to twenty-four years. The participating teachers taught chemistry at different grade levels and in different curricular contexts. Some teachers taught mostly upper secondary students in Grades 11 and 12, and some taught students in a variety of grades, including preparatory classes and Grades 9 through 12. Several participants were involved in both national and international curricula, while others taught exclusively national curricula. The different teaching responsibilities provided the opportunity to capture perspectives from teachers working with diverse student populations and educational programs in the study.

Some teachers were responsible for national and international curricula, others only for the national curriculum. One of the participants was also an assistant principal in addition to his/her teaching duties. Most participants had no formal training on artificial intelligence, but some noted taking part in professional development seminars on educational technologies and basic AI applications. The diversity of teaching experiences, curricular responsibilities, and professional backgrounds enabled a deeper understanding of the opinions and experiences of chemistry teachers with regard to the use of AI-based tools in chemistry education. Table 3.2 presents the summary of the demographic characteristics of in-service chemistry teachers.

Table 3.2 *Demographic Characteristics of In-Service Chemistry Teachers*

Pseudonym	Gender	Years of Experience	Curriculum Taught	AI-Related Training
Aslı	Female	3	National & International	No
Seda	Female	6	National & International	No
Aylin	Female	19	National & International	Introductory Seminar
Mehmet	Male	19	National	No
Ahmet	Male	20	National	Educational Technology Seminar
Fatma	Female	24	National & International	Educational Technology Seminar
Selin	Female	22	National & International	Educational Technology & AI Seminar
Gülşah	Female	7	National & International	Educational Technology & AI Seminar
Özlem	Female	21	National & International	Professional Development Courses
Meltem	Female	21	National & International	No

All participants were chemistry teachers working in private colleges in Ankara, Türkiye.

3.4 Data Collection Tool

Semi-structured interviewing was the preferred method in order to balance consistency and flexibility. The researcher prepared a set of guiding questions beforehand, but also got the opportunity to ask follow-up questions, seek clarifications, and explore issues emerging during the interview process. Semi-structured interviews allow researchers to collect open-ended data and allow participants to describe their experiences and perspectives in their own words (DeJonckheere & Vaughn, 2019). This interview format also provides researchers with the flexibility to probe participants' responses and to obtain more in-depth information when required.

The construction of the interview protocols was guided by the research questions and by the relevant literature on artificial intelligence in education, AI-based tools, and chemistry education. During the process of development, care was taken to ensure that the interview questions were in line with the purpose of the study and could elicit detailed responses from participants. Most of the interview questions were adapted from previous studies on artificial intelligence in education, teachers' perceptions and experiences of AI, AI integration in educational environments, and AI ethics (Chen et al., 2020; Chiu & Chai, 2020; Holmes et al., 2019; Jaber Kamali et al., 2024; Karataş & Yüce, 2024; Kim et al., 2022; Nazaretsky et al., 2022; Zawacki-Richter et al., 2019). Some questions were adopted with minor modifications while others were revised or developed by the researcher to fit the purpose, research questions and chemistry education context of the present study. Interview questions were carefully designed to be coherent and relevant, and to elicit rich and detailed responses from the participants during the development process. Castillo-Montoya (2016) pointed out that interview protocols must be systematically developed and tied to research questions to ensure the production of valuable qualitative data. Therefore, the interview questions were designed to explore participants' awareness of AI-based tools, their perceptions of integrating AI into chemistry education, their

experiences with these tools, perceived benefits and challenges, ethical concerns, and recommendations for future implementation.

The first interview protocol consisted of 23 questions. After developing the interview questions, the protocol was reviewed by the thesis supervisor and an expert in chemistry education. Based on their feedback, some questions were rephrased to improve clarity and comprehensibility, and some questions were divided into more specific questions to allow for more rich and detailed responses. While pilot interviews were not conducted, the expert review process contributed to the quality and relevance of the interview protocol.

Two interview protocols were prepared for the data collection: pre-service chemistry teachers and in-service chemistry teachers. The two protocols were very similar and covered the same research topics. However, some questions were designed specifically for the educational and professional backgrounds of the participants. Therefore, the final interview protocol for pre-service chemistry teachers consisted of 20 questions, and the interview protocol for in-service chemistry teachers consisted of 22 questions. The in-service teacher protocol included additional questions about participants' professional backgrounds and experiences with educational technologies and artificial intelligence.

The interview questions were clustered into several broad themes: participants' background experiences, awareness and understanding of AI-based tools, perceptions on the use of AI in chemistry education, instructional applications of AI-based tools, experiences with these tools, perceived benefits and limitations, ethical considerations, and suggestions for future implementation. Interviews were conducted using open-ended questions to encourage participants to talk more about their views and experiences. Further clarification or elaboration was sought using probing questions. When the participant found it difficult to understand a question, the researcher rephrased the question while maintaining the original meaning of the question to make it easier to communicate and to get more detailed responses.

Examples of interview questions often asked of both participant groups were:

> Have you experienced any positive or negative results, concerns, or limitations while using or considering the use of artificial intelligence in chemistry education?
>
> Have you ever employed any AI-based tools in your chemistry instruction or during your teacher training? If so, could you provide a detailed explanation of the process?
>
> Based on your experience, how can AI be smoothly integrated into education? Suggest ways to improve teacher training for AI in education.
>
> Share any final thoughts on your experience with AI in education not previously mentioned.

The following are some sample interview questions designed for in-service teachers:

> Could you provide a brief overview of your teaching background and current position?
>
> How many years have you been teaching?
>
> Have you received any training or attended any courses related to educational technologies or artificial intelligence?

The following is an example interview question designed for pre-service teachers:

> Have you taken any university courses related to educational technologies or artificial intelligence?

Table 3.3 *Interview Questions According to Themes*

Interview Theme	Interview Questions
Section A: Background Information Related to the Participant	Q1. Could you provide a brief overview of your teaching background and current position? (In-service chemistry teachers only) Q2. How many years have you been teaching? / Which grade are you teaching? (In-service chemistry teachers only) Q3. Have you taken any university courses related to educational technologies or artificial intelligence? (Pre-service chemistry teachers only) Q4. Have you received any training or attended any courses related to educational technologies or artificial intelligence? (In-service chemistry teachers only)
Understanding of Artificial Intelligence	Q5. When you hear the term "artificial intelligence" (AI), what is the first thing that comes to mind? Q6. What types of AI-based tools do you perceive are presently being implemented in the field of education and chemistry education?

Table 3.3 (continued)

Interview Theme	Interview Questions
Teachers' Perceptions of AI-Based Tools	Q7. How do you perceive the integration of AI applications into teaching, and how does this integration shape your teaching style and professional identity?
	Q8. What is your general perspective on the integration of AI tools into chemistry education, and how do you believe these tools could facilitate student learning in chemistry?
	Q9. Do you believe it is necessary to use AI in chemistry education? In what way? Could you elaborate?
	Q10. What are your expectations for the potential benefits of AI technologies in the field of chemistry education?
	Q11. What are the potential disadvantages of AI technologies in the field of chemistry education?

Table 3.3 (continued)

Interview Theme	Interview Questions
Experiences with AI-Based Tools in Chemistry Education	Q12. Have you ever employed any AI-based tools in your chemistry instruction or during your teacher training? If so, could you provide a detailed explanation of the process?
	Q13. Have you experienced any positive and negative consequences, concerns, or constraints when employing or considering the use of AI in the field of chemistry education?
	Q14. In terms of assessment (question preparation, assessment activity preparation, homework assignment, project assignment).
	Q15. In terms of identifying and addressing students' difficulties/conceptual misconceptions.
	Q16. In terms of preparing lessons, experiments, and activities.
	Q17. Have you used them in terms of understanding curriculum-related learning outcomes or subject sequencing?
	Q18. Have you used AI-based tools during lessons?
	Q19. Share any final thoughts on your experience with AI in education not previously mentioned.

Table 3.3 (continued)

Interview Theme	Interview Questions
Recommendations for Effective Integration of Artificial Intelligence in Chemistry Education	Q20. Based on your experience, how can AI be smoothly integrated into education? Q21. What are your suggestions for improving teacher training regarding the use of artificial intelligence in education?
Ethical Considerations Regarding AI Use	Q22. Do you have ethical issues regarding the use of AI tools in the classroom, including automation, bias, or data privacy? Q23. In your opinion, what ethical obligations do educators have when incorporating AI-based tools into their teaching practices?

Appendix A, contain the final interview protocols used in this study. The procedures used in the data collection process are described in the following section.

3.5 Data Collection Procedure

Data were collected between October 2025 and January 2026. Before the data collection, ethics approval for the study was obtained and preparations necessary for participant recruitment and interviewing were made. The interview protocols for the pre-service and in-service chemistry teachers were finalized after expert review and revision.

Participants were recruited using purposive sampling procedures. The pre-service chemistry teachers were chosen from the Chemistry Teacher Education Program at a university. The researcher's thesis supervisor shared information about the study with prospective participants. Those students who volunteered to participate in the study were contacted individually and were informed about the purpose and procedures of the research.

The in-service chemistry teachers were obtained through professional contacts. The researcher contacted the chemistry teachers working at her institution and the chemistry teachers at a different private college in Ankara. The subjects of the study were those teachers who were willing to participate voluntarily.

Prior to each interview, participants were briefed about the study's purpose, the voluntary nature of their participation, the confidentiality of their responses, and their right to withdraw from the study at any time without facing any negative consequences. All participants were asked to provide their consent to participate and recorded in audio and before the interviews.

All interviews were conducted in Turkish, one on one. Interviews were conducted either online using Zoom or in-person, depending on participants' availability and preference. Fourteen interviews were conducted via Zoom, including all nine pre-service chemistry teachers and five in-service chemistry teachers. The other five chemistry teachers still employed were interviewed face-to-face. Interviews were approximately 30 to 40 minutes in length.

The interviews were audio-recorded to ensure that the participants' responses were accurately captured. The online interviews were recorded in audio and video by the recording function of Zoom. For the face-to-face interviews, recordings were made using a mobile phone. In addition to the pre-prepared interview questions, probing questions were sometimes used to clarify participants' responses and to obtain more detailed information when needed.

All interviews were transcribed verbatim after data collection was completed. The interview transcripts were first produced using an automated transcription tool. Then the researcher listened to the original recording and checked each transcript for accuracy and completeness and made the necessary corrections. This process helped to ensure that participants' responses were accurately represented before data analysis.

The main source of data for the content analysis in the present study was the transcripts of the semi-structured interviews. The next section describes the procedures used for data analysis.

The researcher participated actively in every step of the data collection process. The researcher personally contacted each participant through phone or e-mail, informed them about the purpose and procedures of the study, and scheduled the interview times according to the availability of the participants. All interviews were conducted by the researcher either online via Zoom or face-to-face. The researcher followed the semi-structured interview protocol during the interviews, but also asked follow-up questions when clarification or further elaboration was needed. The researcher was also responsible for recording, transcribing, organising and analysing the data collected. Throughout the research process, consistent interview procedures were carefully maintained and participants' responses were reported as accurately as possible.

3.6 Data Analysis

The interview data were analysed using inductive qualitative content analysis. Qualitative content analysis is a systematic approach for analysing qualitative data by identifying patterns, categories, and themes through a detailed examination of participants' responses (Hsieh & Shannon, 2005). In this study, an inductive approach was used since the purpose was to investigate pre-service and in-service chemistry teachers' perceptions and experiences related to the use of AI-based tools

in chemistry education. Categories and themes emerged directly from the interview data, not from pre-existing categories or theoretical frameworks.

Then, after transcription, all interview transcripts were read several times to familiarize the researcher with the data and obtain an overall understanding of the participants' responses. In this step, meaningful statements, recurring ideas and relevant expressions regarding the research question were identified and coded with initial codes. The process of inductive content analysis, as outlined by Elo and Kyngäs (2008), commences with open coding. This involves the researcher meticulously reviewing the data and creating codes that are derived from the participants' answers.

Following the initial coding process, similar codes were compared and grouped together under broader categories. The analysis process was done by constant comparative method. This method involves constant comparison of data segments, codes and sub-categories to identify similarities, differences and patterns in the data (Boeije, 2002). New codes were compared to the previously identified codes and categories and revised where necessary. This iterative process helped refine the coding framework and develop meaningful categories.

The related sub-categories were then clustered into broader categories and sub-themes that represented participants' perceptions, and experiences of AI-based tools in chemistry education. The final thematic structure was developed through repeated examination of the data and constant comparison of participants' responses. The categories and sub-themes were designed to mirror common patterns in the dataset while remaining close to the participants' own statements.

Multiple coding was used as appropriate as some participants' responses represented more than one idea or experience. Here, a single response could be coded under more than one code, category or sub-theme. This approach allowed the researcher to capture the complexity of participants' views without requiring that responses be placed in mutually exclusive categories.

The analysis process was made more transparent by calculating frequencies for each sub-category . The frequencies represent the number of participants who mentioned a particular theme or sub-theme and were used to provide descriptive support for the qualitative findings. The reported frequencies are not statistically significant; they are illustrative of patterns and trends in participants' responses to better realize the differences and similarities to make a connection with the literature.

The process of analysis led to the identification of themes, categories and sub-categories related to the participants' views on artificial intelligence, knowledge of AI-based educational tools, perceptions regarding the use of AI in chemistry education, experiences with AI-based tools, suggestions for effective AI use, and ethical issues associated with AI in educational settings.

Table 3.4 *Coding Protocol*

Theme	Category	Sub-category	Representative initial codes
Teachers' Perceptions Regarding AI in Chemistry Education	Conceptualizations of AI	AI as Digital Applications and Information Systems	AI as application, AI as software, data networks, gathering information, synthesizing information.
		AI as an Assistive and Facilitative Technology	Convenience, practical utilization, AI as assistant, ease of use, AI as helper.
		AI as Robotics and Human-Like Systems	Thinking like humans, robots that are not alive mechanized systems.
	Awareness of AI-Based Educational Tools	Awareness of Generative AI Tools	ChatGPT, Gemini and DeepSeek

Table 3.4 (continued)

Theme	Category	Sub-category	Representative initial codes
Teachers' Perceptions Regarding AI in Chemistry Education (continued)	Awareness of AI-Based Educational Tools (continued)	Confusion Between AI and Educational Simulation Tools	Having trouble differentiating AI from other educational technologies, Associating AI as simulations
		Limited awareness of AI tools	Inadequate knowledge of AI-based tools, uncertainty over AI-based educational tools
		No awareness of AI tools	Inability to identify an AI tools, lack of knowledge of AI based educational resources.
	Perceived Benefits of AI Use	Instructional Support	Lesson planning, material preparation, test preparation, time-saving assistance, and activity planning
		Facilitation of Chemistry Learning	The simplification of abstract ideas, simulations, animations, accessible visual explanations, participation,
	Perceived Risks of AI Use	Risks of Cognitive Dependency	Dependence on AI; decreased critical thinking; surface learning; lack of inquiry
		Risks of Reduced Teacher Oversight	Teachers/Instructors cannot be replaced; pedagogical duty; assessing AI results

Table 3.4 (continued)

Theme	Category	Sub-category	Representative initial codes
Teachers' Perceptions Regarding AI in Chemistry Education (continued)	Ethical Concerns and Responsibilities in AI Integration	Privacy and Data Protection	the gathering of private information, data misuse, data privacy, data leaking
		Academic Honesty	Referencing sources, copying assignments; plagiarism, and intellectual theft
		Accuracy and Reliability of AI Content	Incorrect information; content that has been falsified; information that has been confirmed by academia
		No Ethical Concerns	No ethical issues or concerns were raised
Experiences with AI-Based Tools in Chemistry Education	Instructional Uses of AI-Based Tools	Lesson Planning and Preparation	lesson planning, lesson flow organization, lesson content structure, brainstorming exercises, and getting teaching recommendations modifying lesson plans, implementing AI recommendations, scheduling instruction, pacing instruction, and allocating instructional time

Table 3.4 (continued)

Theme	Category	Sub-category	Representative initial codes
Experiences with AI-Based Tools in Chemistry Education	Instructional Uses of AI-Based Tools (continued)	Assessment and Question Development	Creating alternate questions and exam questions creating assignments, designing assignments, and developing project tasks development of answer keys, rubrics, and flashcards Verifying scientific accuracy; rewording enquiries; and creating a variety of questions
		Experiment, Activity, and Material Design	Ideas for experiments; designs for classroom activities; preparation of worksheets for laboratory activities; lists of resources; simulations of instructional materials; animations; experiment visuals; instructional videos
		Addressing Misconceptions and Learning Difficulties	Common misunderstandings; conceptual ambiguity that simplifies explanations; different representations that rectify misunderstandings; and visual conceptual support
	Experienced Benefits of AI Use	Support for Instructional Planning and Design	Creating lesson plans; creating experiments and activities; Creating evaluation resources

Table 3.4 (continued)

Theme	Category	Sub-category	Representative initial codes
Experiences with AI-Based Tools in Chemistry Education (continued)	Experienced Benefits of AI Use (continued)	Support for Teachers' Own Learning	Acquiring understanding of new ideas; completing content knowledge gaps; and looking for more clarifications
		Support for Effective Concept Explanation	Suggesting alternative explanations; Giving examples and analogies; Explaining concepts for students
	Experienced Challenges of AI Use	Accuracy and Reliability Concerns	Misconceptions; incorrect answers; incorrect explanations checking information; cross-checking sources; comparison with textbooks
		Limitations in AI's Understanding of User Intent	Misinterpreting prompts; Giving answers that are not relevant to the prompt; Need a more specific prompt
		Limitations of Contextual Adaptation	Not adaptable to classroom context; Content inappropriate to students' level; Poor contextualization

Table 3.4 (continued)

Theme	Category	Sub-category	Representative initial codes
Experiences with AI-Based Tools in Chemistry Education (continued)	Experienced Challenges of AI Use (continued)	Need for teaching responsible use of AI	Teaching students how to use AI; Verifying data produced by AI; Promoting ethical and critical use, instructor supervision over critical AI use; avoiding over-reliance, and teaching ethical AI use
	Teacher-related	Teacher Training for AI Competence and Awareness	AI classes or workshops Teacher training Prompt-writing techniques, Teaching responsible AI usage
	Student-related	Training students for responsible use	Developing effective prompts to train students; Promoting ethical and responsible use for students
	Institution-related	Establishing Institutional Conditions for Effective AI Integration	Providing access to technology infrastructure; guaranteeing fair access; creating institutional AI regulations; integrating AI into the curriculum; Monitoring the use of AI

3.7 Trustworthiness of the Study

The term trustworthiness is often used in qualitative research to assess the quality and rigour of a study. Trustworthiness is composed of four criteria: credibility, transferability, dependability, and confirmability. These criteria are often used to show that the qualitative findings are of good quality and trustworthy (Korstjens & Moser, 2018; Shenton, 2004).

3.7.1 Credibility

The level of credibility of the findings is determined by how accurately they reflect the perspectives and experiences of the participants (Shenton, 2004). The study has employed several strategies to enhance its credibility.

First, the interview protocols were reviewed by the researcher's thesis advisor and an expert in chemistry education. Some questions were modified and improved according to the feedback to make them clearer and more consistent with the research objectives.

Second, all interviews were audio recorded and transcribed verbatim. We initially used an automated transcription tool, but each transcript was verified by the researcher while listening to the original recording. Corrections needed to ensure the accuracy of the transcripts were made before analysis.

Third, the researcher was deeply involved in the data during the analysis. The interview transcripts were read and re-read and codes, categories, themes and sub-themes were constantly reviewed and refined. Emerging findings and thematic structures were discussed with the thesis supervisor during analysis.

Finally, the findings section used direct quotes from participants throughout. The use of participants' own words allowed readers to evaluate the connection between the data and the researcher's interpretations.

3.7.2 Dependability

Dependability refers to the stability and consistency of the research process over time (Korstjens & Moser, 2018). Throughout the study, a systematic and transparent procedure for data analysis was followed to enhance the dependability.

Semi-structured interview protocols were used for the interviews. The interview process, transcription procedures, coding procedures, category development and theme generation processes were systematically documented . During analysis, the researcher repeatedly revisited the data and reviewed previously developed codes and categories to ensure consistency in coding decisions. Moreover, the coding frame and the emerging themes were discussed with the thesis supervisor during the analytical process. In addition, two researchers coded the data independently for three participants and they compared their coding. In most cases, it was consistent. In few cases, the inconsistencies were discussed and a consensus was reached.

The storage of interview recordings, transcripts, coding documents and frequency tables also contributed to the transparency and consistency of the study.

3.7.3 Transferability

Transferability refers to the degree to which the findings can be applied to other similar settings and groups of participants (Shenton, 2004). Rather than seeking statistical generalisability, qualitative research seeks to provide sufficient contextual information for readers to determine whether the findings may be relevant to other settings.

Transferability was enhanced by providing rich descriptions of the research context, participant characteristics and sampling procedures. The participants of the study were pre-service chemistry teachers enrolled in the Chemistry Teacher Education Program at a university and in-service chemistry teachers employed in different private colleges in Ankara, Türkiye. The participant section detailed participant

demographics, teaching experience, educational backgrounds, and professional characteristics. Furthermore, the procedures of data collection and analysis were explained in detail so that the readers may assess the applicability of the findings in other educational settings.

3.7.4 Confirmability

Confirmability is the degree to which research findings are based on the data and not the assumptions or biases of the researcher (Korstjens & Moser, 2018).

In this study, themes and subthemes were developed inductively from the responses of participants rather than being derived from pre-determined theoretical categories. The coding decisions were based on the content of the interview transcripts and were constantly checked with the original data during the process of analysis. Direct quotations were used extensively in the findings chapter to provide evidence for the themes and interpretations presented.

Additionally, the coding frame and thematic structure were discussed and reviewed with the thesis supervisor during the analysis. This helped to ensure results were true to the participants' perspectives and remained closely grounded in the original interview data.

3.8 Ethical Considerations

Ethical considerations were considered at every stage of the research process. Ethical approval was obtained from the University's Human Research Ethics Committee prior to data collection. The study was also officially authorised by the Ministry of National Education.

Participation in the study was voluntary. At the beginning of each interview, participants were informed of the purpose of the study, the procedures involved, the voluntary nature of their participation, and their right to withdraw from the study at

any time without any negative consequences . Participants were also informed that the interviews would be recorded and the recordings would be used solely for the purpose of research.

Protection of participants' privacy and confidentiality was a key consideration throughout the study. In line with recommendations for ethical practice in qualitative research, identifying information was removed from the reporting of findings (Shenton, 2004). In order to preserve the anonymity of the participants, pseudonyms were allocated to all participants, which were used throughout the findings and discussion chapters. Names of individuals, schools, and institutions were deleted from interview transcripts and research reports to ensure anonymity.

Data security was also well guarded. Audio recordings, interview transcripts, coding documents and related research material were kept on the researcher's password protected personal computer. Only the researcher had access to the data, and it was only for academic purposes.

All interviews were conducted in Turkish and the thesis was written in English. So, the quotations from participants in the findings chapter were translated from Turkish to English by the researcher. The translation was done with special care to ensure the original meaning, intent and context of the statements of the participants were preserved. This approach enabled us to accurately capture participants' views, while also maintaining the confidentiality of the original interview data.

The study was carried out in accordance with the principles of qualitative research, such as voluntary participation, confidentiality and anonymity, informed consent, and responsible data management (Korstjens & Moser, 2018; Shenton, 2004).

3.9 Limitations of the Study

Several limitations should be taken into account when interpreting the findings of this study.

First, this study only adopted semi-structured interviews for data collection. Interviews provided rich and nuanced data on participants' opinions and experiences, but other sources of data such as classroom observations, document analysis or the analysis of AI-generated instructional materials could have provided further insights and allowed for methodological triangulation.

Secondly, the findings were based on the self-reported experiences and perceptions of participants on the use of AI-based tools in chemistry education. Thus, the study depended on participants' self-descriptions of their practices rather than direct observations of their actual use of AI tools in instructional settings. Hence, the participants' responses could have been affected by their own interpretation, memories or personal perceptions.

Thirdly, another limitation of the present study is that all the in-service chemistry teachers were recruited from private schools in Ankara, which may have affected the findings, because their experiences and perceptions of AI integration may reflect the specific educational environments in which they work.

Lastly, the field of artificial intelligence is developing rapidly with new AI-based tools and educational applications appearing all the time. The technological context at the time the data was collected (October 2025-January 2026) may have affected the participants' views and experiences. As technologies continue to develop and become more commonly integrated in educational settings, perceptions and experiences of AI-based tools may evolve.

On the other hand, the research provides important perspectives on the views and experiences of Turkish pre-service and in-service chemistry teachers in using AI-based tools in chemistry education and adds to the growing number of studies on artificial intelligence in science education.

3.10 Assumptions of this Study

The study was built on two major presumptions. Firstly, the purpose of purposive sampling is to select participants who are likely to offer rich and meaningful information relevant to the purpose of the study and it was anticipated that the participants would be information-rich cases, (Gentles et al., 2015). Secondly, it was assumed that the participants answered the questions of the interview truthfully and openly, sharing their true thoughts and experiences about the application of AI-based tools in chemistry education.

CHAPTER 4

RESULTS

This chapter presents the results of the analysis that was obtained from the data collected in the interviews. The analysis results are categorised into three themes: "Teachers' Perceptions Regarding AI in Chemistry Education", "Experiences with AI-Based Tools in Chemistry Education" and "Recommendations for Effective AI Integration in Education". Each theme will be categorised under a general theme which will be grouped under major topic. In this chapter you can see the information which showed the themes, categories, subcategories, and participants' distribution of identified categories.

4.1 Teachers' Perceptions Regarding AI in Chemistry Education

Depending on their experience, familiarity and understanding of technology, participants described artificial intelligence (AI) differently. The results indicated that participants' main conceptualizations of AI were robotic or human-like systems, assistive and facilitating technologies, and digital applications and information systems. The most commonly expressed perception of pre-service and in-service chemistry teachers was that AI is digital applications and information systems.

4.1.1 Conceptualizations of AI

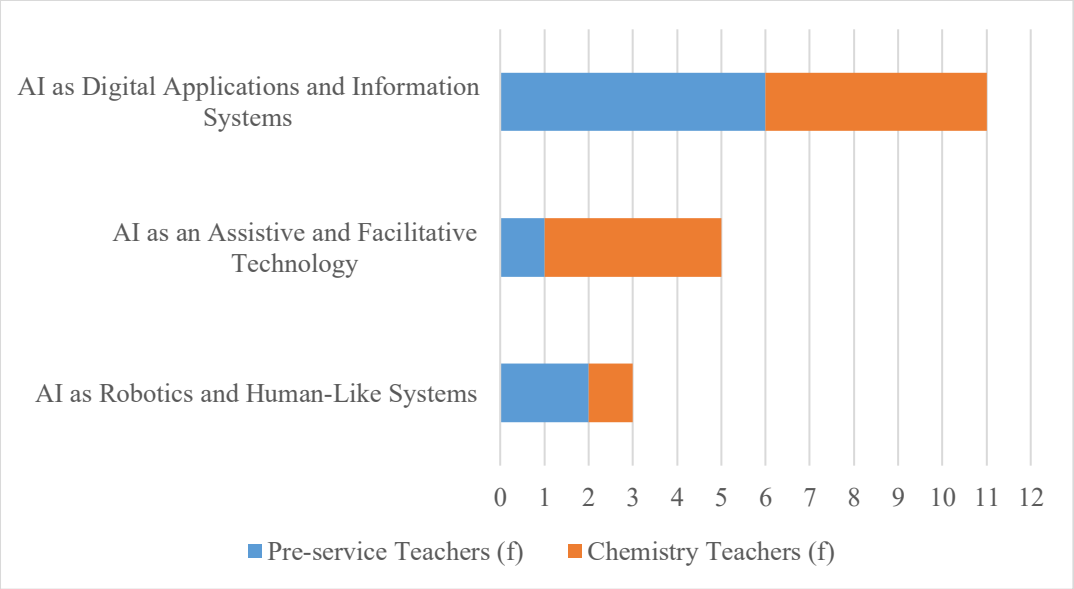

Figure 4.1 *Pre-Service and ın-service chemistry teachers' perspectives towards artificial ıntelligence in chemistry education*

4.1.1.1 AI as Digital Applications and Information Processing Systems

Eleven participants, which are 6 pre-service and 5 in-service chemistry teachers, associated artificial intelligence (AI) with software, digital applications and information processing technology. This category is common for both groups and are in the similar frequency. When it came to defining AI, participants often referenced programs such as Gemini, Siri and ChatGPT. Several participants also mentioned AI's ability to collect, organize, and present information. One of the preservice chemistry teachers described AI as:

"AI applications like ChatGPT or Gemini are the first ones that come to mind." (Ece, pre-service chemistry teacher)

"When we talk about artificial intelligence, I would say that what we are essentially thinking of it is gathering people's thoughts from platforms like Google and presenting them to us as a data network." (Elif, pre-service chemistry teacher)

Likewise, Fatma, a chemistry teacher, explained AI as:

"I think artificial intelligence is a system that filters and synthesizes the information already existing in computers according to the questions being asked."(Fatma, in-service chemistry teacher)

Results show that the participants mainly perceived artificial intelligence through digital platforms and information processing systems.

4.1.1.2 AI as an Assistive and Facilitative Technology

Five participants, which are one pre-service and four in-service chemistry teachers, considered AI as a useful technology that makes tasks easier and helps users in many situations. This category predominantly appeared amoung the in-service chemistry teacher. Participants pointed out the useful benefits and ease provided by AI technology. For example, one of the pre-service chemistry teachers gave the following explanations:

> *I actually think of artificial intelligence as an assistant. That's how I plan to use it more. But people can also see AI as a friend. They can also see it as a mentor they can consult. It's a concept that varies greatly from job to job, but in my opinion, I employed something more like an assistant. (Cihan, pre-service chemistry teacher)*

The above excerpt indicates that AI was described as an assistant to plan. However, while only one pre-service teacher had this idea, four in-service teachers described AI as a technology that makes tasks easier. For example, one of the in-service teachers explained:

Selin mentioned the convenience that AI has provided and explainded:

"Honestly the first thing that comes to my mind is convenience. "This is a technology that really makes life so much easier for us." (Selin, in-service Chemistry teacher)

The results indicated that pre-service chemistry teachers were less likely than in-service chemistry teachers to consider AI as a helpful and supporting tool. Participants in this category were focused on practical use of AI and how it can help people in their daily and work lives and ease their tasks. This difference may be linked to the professional experiences of in-service teachers who seem to highlight the useful and practical benefits of AI technologies.

4.1.1.3 AI as Robotics and Human-Like Systems

Three participants, which are two pre-service and one in-service chemistry teachers, associated AI with mechanized devices, robots, and human-like cognitive skills. This category's participants concentrated on the autonomous and human elements of AI.

For example, when asked to define AI, one of the pre-service teachers, Emre, described AI visually in relation to robots and mechanization:

"The first thing that came to my mind was a robot. Then I started thinking about written and visual content and coding systems."

Similarly, one of the in-service teachers assocaited AI with robots:

"I think of something mechanized. Visually, robots come to my mind." (Meltem, in-service chemistry teacher)

On the other hand, another pre-service teacher perceived AI as non-living things that can think:

"It feels strange to me that something non-living can think like humans. Thinking feels like something unique to humans." (Zeynep, pre-service chemistry teacher)

Compared to the other categories, a smaller percentage of participants thought AI was a robotic system and a human-like system. One chemistry teacher and two pre-service chemistry teachers connected artificial intelligence (AI) to robots, automated systems, and the capacity for independent thought. Perceptions of AI as a system capable of mimicking human thought and behavior were reflected in their answers.

4.1.2 Awareness of AI-Based Educational Tools

The responses of the participants showed varying degrees of knowledge of AI-based educational technologies and chemistry instruction. Four sub-categories emerged from their responses: limited awareness of AI-based teaching tools, awareness of generative AI tools, awareness of visualization and simulation tools and no awarness of AI tools.

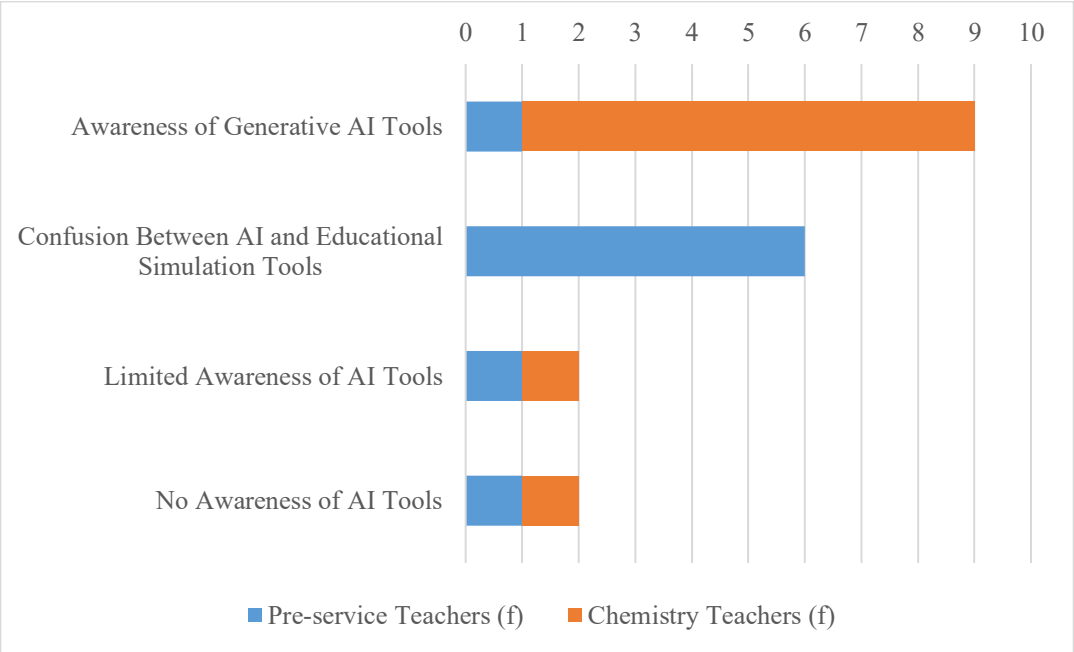

Figure 4.2 *Pre-Service and in-service chemistry teachers' awareness Towards Artificial intelligence in chemistry education*

4.1.2.1 Awareness of Generative AI Tools

The most frequently mentioned was awareness of generative AI technologies. Nine chemistry teachers (eight in service and one pre-service) cited AI programs such as ChatGPT, Gemini, DeepSeek, etc. In this category, participants commonly named AI tools based on popular generative AI platforms rather than chemistry-specific applications. Pre-service chemistry teacher Merve gave the following explanations:

"Mostly I use ChatGPT. For example, I ask myself how can I improve a lesson I want to teach? I also use DeepSeek and Gemini because it has a free student version for a year."

Similarly, one of the chemistry teachers explained:

"I do not use a tool directly for chemistry. I cannot name one. However, we sometimes use ChatGPT for preparing lesson plans, annual plans, tests, or written exam examples. ChatGPT or Gemini is enough for us at the moment." (Mehmet, in-service chemistry teacher)

These responses show that participants who were aware of AI-based tools mostly referred to general-purpose generative AI applications rather than tools designed specifically for chemistry education.

4.1.2.2 Confusion Between AI and Educational Simulation Tools

Six pre-service chemistry teachers integrated AI-based tools with simulations, and animations. The participants in this area often referred to technologies such as PhET, simulations, and animations, used to visualize the ideas of chemistry. Some participants also expressed doubt over whether simulations and animations should be considered AI-based tools. One of the pre-service chemistry teachers explained AI tools as simulations and animations:

"There are some simulations that we use in lessons. Our teacher used to teach through animations, and visualizing the topics made my learning much more effective." (Zeynep, pre-service chemistry teacher)

Another similar response from a pre-serivce chemistry teacher was:

"I think there is PhET, the simulation tool we use. That is the first thing that comes to my mind. I cannot give another example." (Ece, pre-service chemistry teacher)

Similarly, another pre-service teacher associating AI tools with simulations had some doubts whether simulations could be considered as AI:

"I do not know much, but simulations may be examples. I am not sure whether simulations are counted as artificial intelligence, but we use them a lot if they are considered AI." (Derya, pre-service chemistry teacher)

Only pre-service chemistry teachers highlighted simulations, animations, , while in-service chemistry teachers mostly emphasized generative AI programs like Gemini and ChatGPT. This result shows that pre-service chemistry teachers tended to link interactive educational simulations and animations with AI-based teaching technologies., making them confused about simulations and animations withAI tools.

4.1.2.3 Limited awareness of AI tools

Two participants had limited awareness about the AI-based tools used in education and in the field of chemistry education. One pre-service chemistry teachers and one chemistry teachers, which shows similar frequency in both pre-service and in-service chemistry teachers, said that they did not know much specific AI-based tools or could not give clear examples. Emre as a only one pre-service chemistry teacher stated that:

"I don't know much about AI-based tools. I don't know them that well. We used Kendra as software, but as far as I know it's not AI-based. Other than that I don't really have much information." (Emre, pre-service chemistry teacher)

Similarly,

"We had training on Madlen, but other than that I don't know too well honestly." (Fatma, in-service chemistry teacher)

These answers show that participants were not very aware of AI-based tools, especially those developed for the use in chemistry education.

4.1.2.4 No awareness of AI tools

Two participants had no awareness about the AI-based tools used in education and in the field of chemistry education. One pre-service chemistry teachers and one chemistry teachers, which shows this category was equally frequently, said that they did not know AI tools. Elif, pre-service chemistry teacher, explained that:

"Unfortunately, I cannot say exactly. "I don't really know so I can't say anything about that." (Elif, pre-service chemistry teacher)

Likewise one in-service chemistry teachers also stated that:

"I don't know about those tools." (Seda, in-service chemistry teacher)

4.1.3 Perceived Benefits of AI Use

The participants' answers to the inclusion of AI-powered tools in chemistry education showed positive and negative perspectives on the use of artificial intelligence in the process of teaching and learning. Participants primarily saw AI as a positive and supportive educational tool. The analysis of the interviews generated two sub-themes: Instructional Support, Facilitation of Chemistry Learning.

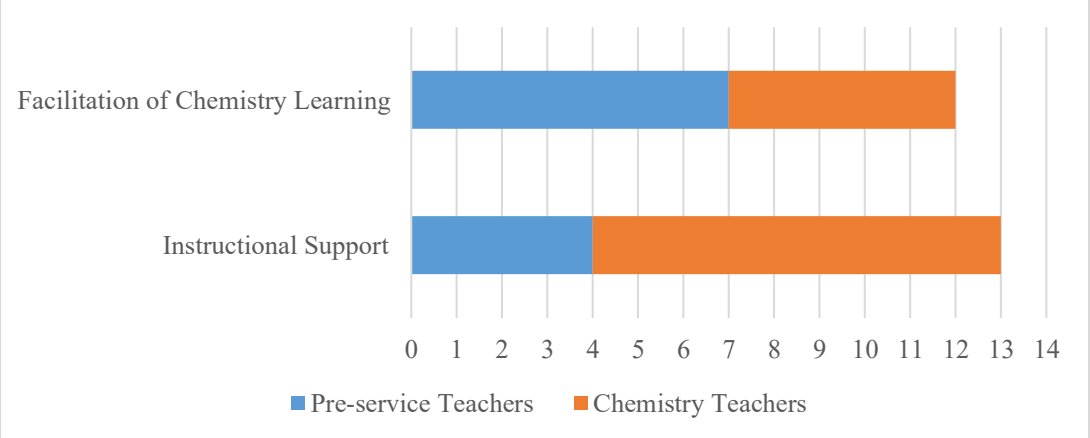

Figure 4.3 *Perceived benefits of AI usage in the chemistry education*

Because participants frequently expressed different opinions about AI integration in a single response, several participants contributed to more than one sub-theme. In other words, rather than being mutually exclusive participant categories, frequencies represent theme presence.

4.1.3.1 Instructional Support

For thirteen participants,four pre-service and nine in-service chemistry teachers, AI-based tools were considered as supportive technologies that help in instructional processes and reduce teachers' workload. This category was mainly supported by in-service chemistry teachers, Participants frequently said that AI tools were useful for lesson planning, preparing instructional materials, writing test questions, organising classroom activities, and saving time in the preparation process. Pre-service chemistry teachers and chemistry teachers perceived AI as an assistant-like system that supports rather than replaces teaching. Some of the responses were:

"I think ChatGPT may be helpful while preparing lessons. ChatGPT helps improve an activity or explanation of a topic in a different way ." (Merve, pre-service chemistry teacher)

"*I believe AI-based tools such as ChatGPT and Gemini are practical for preparing lesson plans, tests, and written examinations because they can save teachers considerable time."* (Mehmet, in-service chemistry teacher)

Similarly, Özlem added that AI is a helpful teaching tool, pointing out:

"I think it is useful . It helps both teachers and students during the research and preparation processes."

Some participants also noted that AI applications assist in instructional efficiency by helping teachers find information more quickly and better organise educational content. The findings indicate that participants mainly perceived AI as a pedagogical support tool that assists instructional practices.

4.1.3.2 Facilitation of Chemistry Learning

Seven pre-service and five in-service chemistry teacher also perceived AI-based tools as technologies to facilitate chemistry learning with support for visualisation, concretisation, interaction, and accessibility. In particular, pre-service chemistry teachers associated AI-supported tools with simulations, animations and visual learning environments. Participants pointed out that AI-supported educational technologies can help students to better comprehend abstract chemistry concepts and boost student engagement in lessons.

"…There are some simulations that we use in lessons. Our teacher used to teach through animations, and visualizing the topics made my learning much more effective." (Zeynep, pre-service chemistry teacher)

Ece also said:

"I think we have this simulation tool we use, PhET. That's the first thing that comes to mind."(Ece, pre-service chemistry teacher)

Cihan also highlighted the significance of simulations and interactive systems in chemistry education and said:

"AI is being embedded in simulations. "These systems allow students to manipulate different variables and get different outcomes." (Cihan, pre-service chemistry teacher)

Among the participants, chemistry teachers mainly mentioned the role of AI in improving accessibility and supporting students' understanding of topics in chemistry. Selin explained similarly:

"AI applications simplify many things for students. They can find information faster and engage with texts more easily." (Selin, in-service chemistry teacher)

Specifically, pre-service chemistry teachers were more likely to emphasise simulations, animations, and visual learning environments, whereas chemistry teachers were more likely to highlight the useful and encouraging aspects of AI applications in chemistry teaching. The majority of participants believed that AI-based instructional tools could enhance chemistry learning through accessibility, engagement, and visualisation.

4.1.4 Perceived Risks of AI Use

The participants' responses to the use of AI-powered tools in chemistry education indicated concerns about the possible risks associated with the use of artificial intelligence during the course of teaching and learning. Analysis of the interviews yielded two sub-themes: Risks of Cognitive Dependency and Risks of Reduced Teacher Oversight.

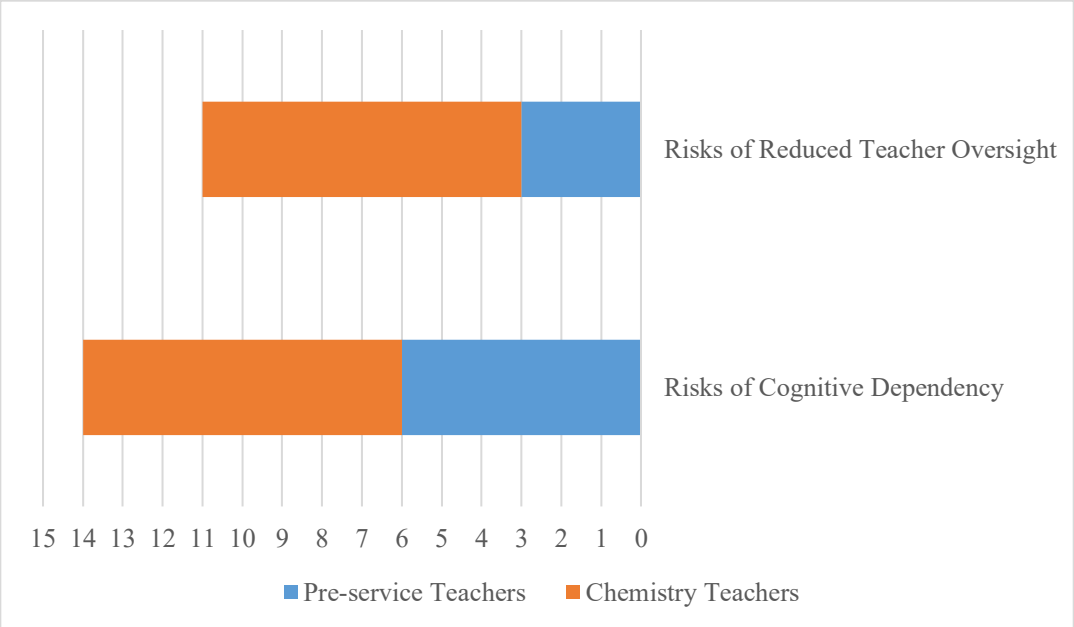

Figure 4.4 *Perceived risk of AI usage in the chemistry education*

4.1.4.1 Risks of Cognitive Dependency

Although most participants, six pre-service and eight in-service chemistry teachers, had favourable opinions on AI integration, many expressed worries about potential harm to students' cognitive and learning abilities. Issues including students' reliance on AI, diminished critical thinking, surface learning, false information, and less effort during the learning process were commonly highlighted by participants. Elif, a pre-service chemistry teacher, shared concerns about over-dependence on AI tools and said:

"Students may become too dependent on these systems instead of thinking on their own."

Another concern was about the false information AI can produce:

"Sometimes students directly copy information without questioning whether it is correct or not." (Zeynep, pre-service chemistry teacher)

Similar issues were also highlighted by a number of chemistry teachers. According to Fatma:

"...Students may stop researching or thinking deeply if they rely too much on artificial intelligence." (Fatma, in-chemistry teacher)

As well, Gülşah explained:

"AI can sometimes provide incorrect information, and students may not always realize whether the information is accurate."

Additionally, some participants mentioned that students problem-solving, interpretation, and analytical abilities might be impacted if AI is used excessively. As a result, the participants stressed the importance of using AI in education in a conscious and controlled manner.

4.1.4.2 Risk of reduced teacher oversight

Another important finding was the emphasis on the continuing importance of chemistry teachers in the context of the growing use of AI in the classroom. Both pre-service and in-service chemistry teachers, three pre-service and eight in-service chemistry teachers, respectively, frequently stated that AI should be a supportive tool and teachers would still play an important role in the teaching and learning process.

"I see artificial intelligence more like an assistant rather than something that replaces people."(Cihan, preservice chemistry teacher)

Likely Aylin expressed:

"AI can make our work easier, but it cannot replace the teacher because students still need guidance." (Aylin, in-service chemistry teacher)

Selin, is a chemistry teacher, also emphasized the irreplaceable role of teachers and stated:

"Technology is developing very quickly, but students still need teachers to guide them correctly." (Selin, in-service chemistry teacher)

Last but not least, such results indicate that participants, in general, perceived AI as an educational technology that supports education, not as a replacement for teachers. The integration of AI-based tools was growing, but teacher guidance, professional judgement, and pedagogical responsibility continued to be indispensable elements of chemistry education.

Interestingly, in-service chemistry teachers were more likely to talk about the future role of teachers in an AI-supported educational environment than pre-service chemistry teachers. Some serving teachers raised concerns that are often discussed in society about the possibility of AI replacing teachers, but in general, they emphasised the importance of AI as a supportive tool, not a replacement for teachers. Teacher guidance, pedagogical decision-making siland professional judgement in chemistry education remain of continuing importance, according to participants.

4.1.5 Ethical Concerns and Responsibilities in AI Integration

Participants were asked about their ethical concerns related to the use of artificial intelligence in educational settings and the ethical responsibilities that teachers should take into consideration when integrating AI-based tools into their teaching practices. The analysis of the interview data revealed four major sub-categories, namely, Privacy and Data Protection, Academic Honesty, Accuracy and Reliability of AI Content. In addition to these sub-categories, some participants mentioned that they have no major ethical concerns regarding the use of AI in education.

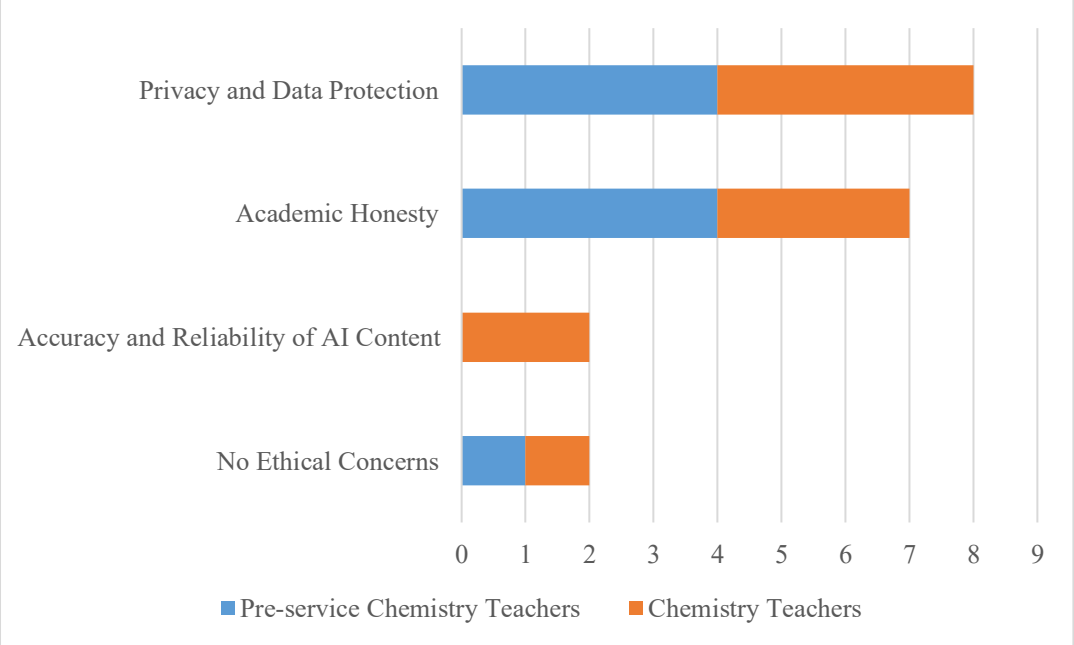

Figure 4.5 *Distribution of participant groups' ethical concerns and responsibilities in AI integration according to dominant ethical concern.*

4.1.5.1 Privacy and Data Protection

The most common ethical concern mentioned by participants was privacy and data protection. Four In-service chemistry teachers and four pre-service chemistry teachers, showing equal frequency, both talked about the possible dangers of accessing private information via AI systems. Participants emphasised the need for

teachers to protect private information while utilising AI-based tools in classrooms and voiced worries about the gathering, storing, and potential misuse of student data. One of the pre-service teachers explained:

"I have not experienced an ethical problem directly. However, AI systems seem capable of accessing personal information. When using computers, they may collect our data, and this could create concerns." (Elif, pre-service chemistry teacher)

Similarly, Merve explained worry about extensive data collection:

> *If students continuously enter highly personal information into AI systems, this could even be considered a form of data leakage. We unintentionally share many personal thoughts with artificial intelligence, and I do not know what the consequences of this data collection might be ten years from now. (Merve, pre-service chemistry teacher)*

Gülşah highlighted common concerns among chemistry instructors:

"I would be concerned about data privacy if students used AI in class using their personal accounts because everything entered into the system becomes data."

Participants also stated the importance of teachers not sharing students' identities, academic records and other confidential information when using AI-based tools. Overall, privacy and data protection were perceived as important ethical issues in the integration of AI into chemistry education.

4.1.5.2 Academic Honesty

One of the subjects was academic honesty. The participants (four pre-service and three in-service chemistry teachers) discussed topics such as plagiarism, intellectual property, use of educational materials without permission and citing sources when using AI generated content. One of the pre-service teachers gave the following explanations:

"Information can be obtained without citing sources. This may lead to plagiarism and what we call intellectual theft. Students may simply copy and paste assignments without doing the work themselves." (Zeynep, pre-service chemistry teacher)

Cihan also explained related to academic integrity and attribution:

"Using information generated by AI without acknowledging the source is no different from taking information from an article and inserting it into my own work without permission." (Cihan, pre-service chemistry teacher)

Aylin directly provided the value of encouraging intellectual work among chemistry teachers:

"The most important issue is respect for effort. AI outputs are built upon studies previously uploaded to online platforms. Therefore, references and citations should always be acknowledged." (Aylin, in-service chemistry teacher)

Another example can be given from other chemistry teacher:

"Taking questions from a published book and asking AI to modify them raises ethical concerns because someone has already invested effort in producing those materials." (Mehmet, in-service chemistry teacher)

Participants also stressed that teachers should set an example of moral behaviour by citing their sources and using AI-generated content responsibly. As a result, attribution and academic honesty become crucial moral responsibilities related to AI integration.

4.1.5.3 Accuracy and Reliability of AI Content

A smaller number of participants(two in-service chemistry teachers only) were mostly concerned with how accurate and reliable the information produced by AI is. These participants were concerned about inaccurate, misleading or non-academic verified information that may impact students' learning. There is no pre-service

chemistry teacher shared accuracy and reliability of AI content about the ethical concerns and responsibilities.

"My biggest concern is the accuracy of the information. I do not believe that all information provided by AI systems has been academically verified." (Özlem, in-service chemistry teacher)

Likewise, Meltem warned about the risks of misinformation:

"AI can make something that never happened appear as if it actually happened. It can create content that presents non-existent events as reality."

The significance of critically assessing AI-generated outputs prior to incorporating them into instructional methods was emphasised by participants in this subject. As a result, it was acknowledged that teachers who use AI-based technologies have an ethical need to guarantee the accuracy and reliability of the information.

4.1.5.4 No Ethical Concerns

Some participants (equal amount of frequency, one pre-service and one in-service chemistry teacher) mentioned that they didn't perceive any major ethical issues with using AI in educational contexts. Ceren, a pre-service chemistry teacher stated that:

"I don't think I have any ethical problems."

Similarly, Seda, a chemistry teacher, said:

"No, nothing I can think of at the moment."

In general, these participants saw AI as a supportive educational tool and did not report specific ethical issues concerning its use in the classroom.

4.2 Experiences with AI-Based Tools in Chemistry Education

Analysis of participants' responses identified three main categories relating to their experiences with AI-based tools in chemistry education: Instructional Uses of AI Tools, Experienced Benefits of AI Use, and Experienced Challenges of AI Use.

4.2.1 Instructional Uses of AI-Based Tools

The first category, Instructional Uses of AI-Based Tools, was further divided into four sub-categories: lesson planning and preparation, assessment and question development, experiment, activity and material design, and addressing misconceptions and learning difficulties.

4.2.1.1 Lesson Planning and Preparation

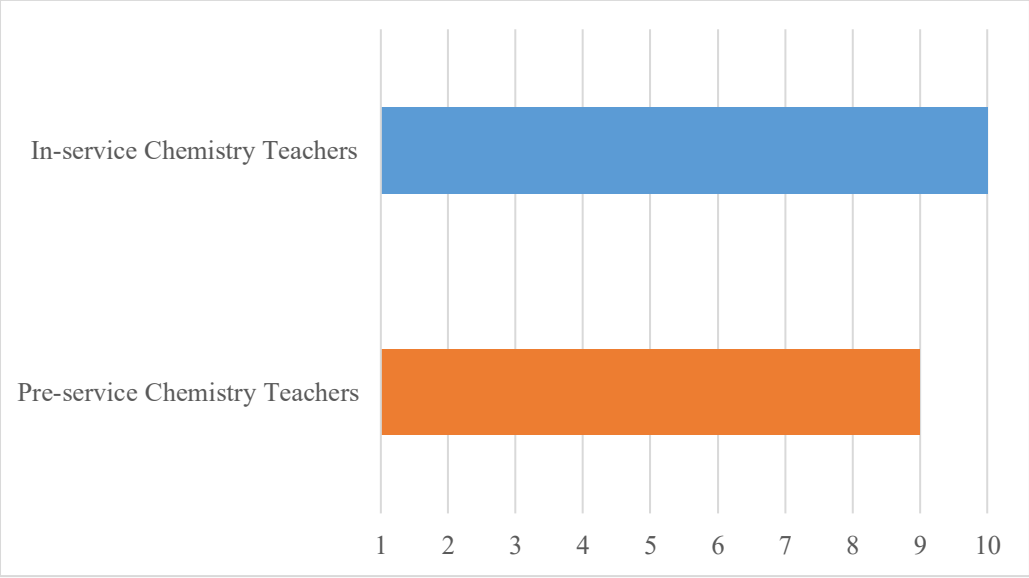

Figure 4.6 *Lesson planning and preparation of pre-service and in-service chemistry teachers in chemistry education*

All participants reported the use of AI-based tools to support activities for lesson planning/preparation. Both pre-service and in-service chemistry teachers reported the use of AI tools in organising lesson content, organising instructional sequences,

generating lesson ideas, improving existing lesson plans, and allocating instructional time.

Pre-service chemistry teachers frequently cited AI tools as a supportive resource in lesson planning rather than depending on them to produce a full lesson plan. Participants often described a process of first generating their own ideas and then using AI tools to refine, reorganise, or expand on these ideas. For example, Zeynep explained how AI was used in the process of preparing a lesson based on the 5E instructional model:

"We asked ChatGPT what we could do with the 5E model. It made a plan for us. We didn't follow it exactly, because we had our own ideas too. We talked about it and used some of it." (Zeynep, preservice chemistry teacher)

Similarly, Defne said she used AI suggestions to organise the whole structure of a lesson plan:

"I had some ideas already, but I still needed an outline for preparing a lesson plan. I did that with AI and combined their suggestions with my ideas. That way I completed the process in less time." (Defne, preservice chemistry teacher)

Some pre-service teachers also used AI tools to enhance the flow of lessons and transitions in instruction. Defne, for example, said:

"Sometimes when I prepared the steps myself, the transitions between them were not very smooth. It gave me ideas on how to jump from questions, videos and activities." (Defne, preservice chemistry teacher)

Other participants described the usefulness of AI in organising sequences of lessons and pacing instruction.

"I told it the subject and that I was going to teach it to students. I asked it to make me a lesson plan and to time the lesson." (Ceren, preservice chemistry teacher)

For example, Emre explained how he uses AI to determine lesson progression and create links between concepts:

> *First I review the topic myself. Then I ask AI to help me with the flow of a lesson. I ask about how to present the lesson, what to teach first, and how to tie in the upcoming subjects with concepts the students have already learned. (Emre, preservice chemistry teacher)*

Similar experiences were reported by in service chemistry teachers . AI tools were often used to organise the content of lessons, adapt the instructional materials to the needs of the students, and support planning decisions. However, participants generally highlighted that AI-generated suggestions were changed and adapted before implementation. For example, Özlem teacher expressed that:

"We use it in the preparation of lesson plans, but not by taking everything straight off. "We see what has been done and change it according to our own lesson." (Özlem, in-service chemistry teacher)

Overall the participants viewed the AI-based tools as useful planning resources that helped them to structure lessons, generate instructional ideas and improve lesson planning processes. The AI tools were used primarily to assist teachers' planning decisions in both participant groups, not to substitute their professional judgement in lesson design.

4.2.1.2 Assessment and Question Development

The second sub-category under Instructional uses was Assessment and Question Development. In this sub-category, participants mentioned using AI-based tools to generate exam-style questions, tasks for homework, project tasks, rubrics, answer keys, flashcards, and assessment-related prompts.

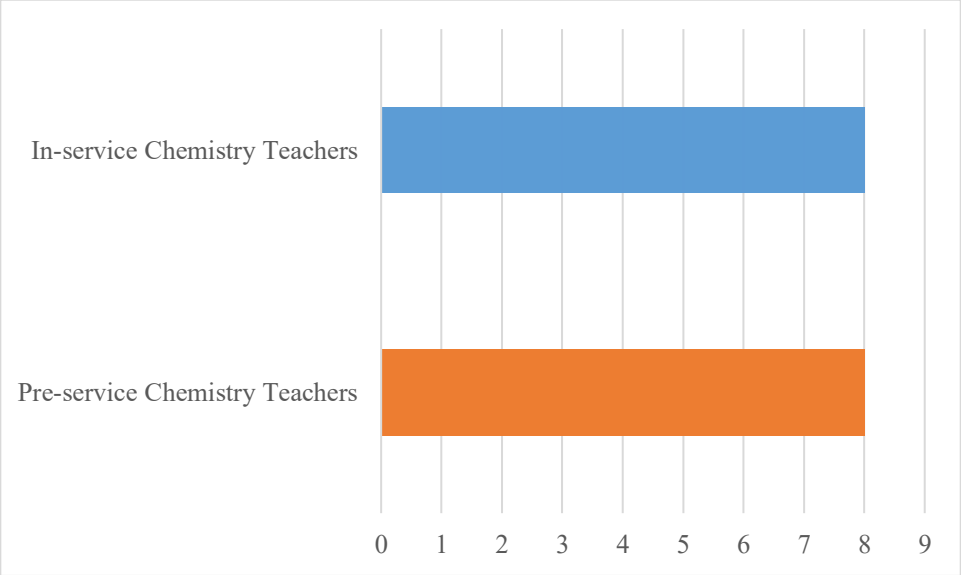

Figure 4.7 *This graph shows that assesment and question development related to experience for AI use both pre service and inservice chemistry teachers.*

Most of the participants(eight pre-service and eight in-service chemistry teacher) in both groups reported using AI tools for assessment-related purposes. Pre-service chemistry teachers used AI to develop questions of different cognitive levels, to prepare homework tasks or to adapt AI-generated questions according to the student level. For example, Ece said she used AI when preparing evaluation questions based on Bloom's taxonomy:

> *In the assessment section we had to formulate questions according to Bloom's taxonomy. In preparing these questions, I have given some prompts and I have specified the types of questions I wanted based on the level of the students. The questions were actually given to me by AI. I was very pleased with them and used them that way. (Ece, preservice chemistry teacher)*

Like Merve, she said that she asked AI for ideas for questions but then generally adapted the questions before using them:

> *Sometimes I ask, what can I ask about this subject. Although it does not usually pose very good questions. The questions are generally at the most elementary level of knowledge and understanding. Sometimes I take them and*

make them a different kind of question and use them. (Merve, preservice chemistry teacher)

Some pre-service teachers generated exam questions as well as homework or assignments using AI. Ceren said: "I asked it to create a sample assignment on endothermic and exothermic reactions.

"It gave an assignment where the students had to relate the topic with other courses and explain why the reaction is endothermic or exothermic and draw graphs." (Ceren, preservice chemistry teacher)

In-service chemistry teachers also reported using AI for question development and assessment. AI tools were used for test writing, checking questions, preparing answer keys, rubrics and designing project assignments. Mehmet explained how he uses AI to generate questions of different difficulty levels:

"We gave the topic and the learning outcomes during the test preparation. "I said I want this many easy questions, this many medium, this many difficult and AI gave me options." (Mehmet, in-service chemistry teacher)

Özlem stressed that she did not use AI-generated questions directly, but used AI to test, revise and diversify her own questions:

> When I was preparing questions for students, I added a question that I wrote myself. I tell it to rephrase the question with another example. I also try to test if there is a scientific mistake in the question. I never use anything from it directly, I use it for testing or to diversify questions. (Özlem, in-service chemistry teacher)

Fatma said she uses AI for rubrics, particularly for assignments:

"We used it several times to create rubrics. We put in the assignment and the things we wanted and it created a rubric for us." (Fatma, in-service chemistry teacher)

Overall, participants used AI-based tools in assessment-related processes primarily as a source of question ideas, alternative formats, rubrics, and project structures. However, both pre-service and in-service teachers usually said that AI-generated assessment materials needed to be revised, adapted or verified before use.

4.2.1.3 Experiment, Activity, and Material Design

The third sub-categories recognised under instructional uses of AI-based tools was the Design of Experiment, Activity, and Material. This sub-category focused on the experiences of participants in using AI-based tools for designing experiments, generating classroom activities, preparing laboratory materials, producing instructional visuals and integrating simulations and animations in teaching chemistry.

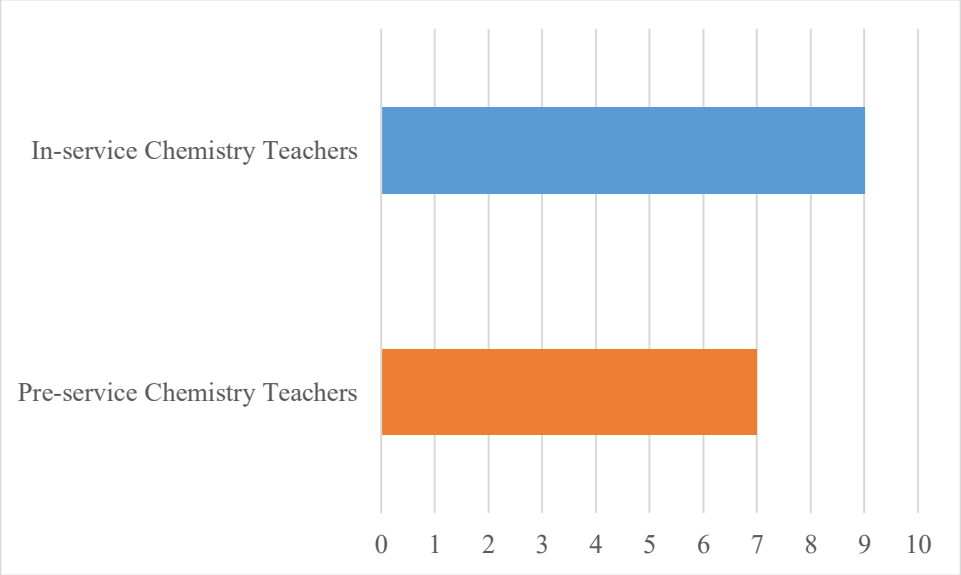

Figure 4.8 *Pre-service and in-service chemistry teacher experiences relate to experiment, activity, and material Design*

Both seven pre-service and nine (almost all) in-service chemistry teachers reported "frequent use" of AI-based tools to support the preparation of experiments and instructional materials. Participants reported using AI for experiment idea

generation, adaptation of laboratory activities, worksheet preparation, visual material creation, and identification of appropriate classroom demonstrations.

Pre-service teachers often employed AI tools to support the design of experiments and activities in lesson plans. Zeynep said AI was useful in figuring out how to run the exploration phase of a lesson:

"We could not decide what kind of experiment we should do in the exploration stage. This gave us a lot of ideas for experiments. We chose one of them and tailored it for our lesson." (Zeynep, preservice chemistry teacher)

Merve also explained that they used AI to generate ideas for activities and experiments:

"I ask myself what activity can I do for this topic? What kind of experiment can I design for the students? Usually it gives several alternatives, and I modify them for my lesson." (Merve, preservice chemistry teacher)

Other participants mentioned using AI to locate simulations, animations, and visual materials that could be helpful in instruction. For example Defne said;

"I incorporated simulations and animations into the lesson. "AI has been great for creating material lists and keeping the activities organised while preparing experiment worksheets." (Defne, preservice chemistry teacher)

Similar uses were reported by in-service chemistry teachers. However, several teachers pointed to the usefulness of AI tools for preparation of laboratories worksheet materials. Aylin said:

"I told it to think of other experiments with the same materials. It proposed three or four experiments that might be made with the materials available." (Aylin, in-service chemistry teacher)

Selin said she also relied on AI to pick appropriate materials and experimental process:

"I wondered which of the five metals would have the desired effect. It helped me to decide which materials were more proper for the experiment." (Selin, in-service chemistry teacher)

Teachers also reported using visuals and videos generated by artificial intelligence to support laboratory instruction. Özlem explained:

"I can give AI pictures and videos of experiments that I have not done myself. "This makes it easier for students to see the process." (Özlem, in-service chemistry teacher)

Participants reported using AI-based tools as useful resources for idea generation for experiments, design of classroom activities, preparation of instructional materials, and assistance in laboratory-related teaching practices.

4.2.1.4 Addressing Misconceptions and Learning Difficulties

The fourth sub-category under instructional uses of AI-based tools was Addressing Learning Difficulties and Misconceptions. This sub-category was related to participants' experiences of using AI tools to identify misconceptions, anticipate learning difficulties, offer alternative explanations, and support students' conceptual understanding.

Compared with the previous sub-category, fewer participants reported using AI-based tools to identify and address misconceptions. However, a few participants described using AI to explore common misconceptions of chemistry concepts and to develop strategies to support student understanding. Six pre-service chemistry teachers stated that they used AI to deal with misconceptions and learning difficulties, and three in-service chemistry teachers reported this use. Therefore, this category was reported by twice as many pre-service teachers as in-service chemistry teachers.

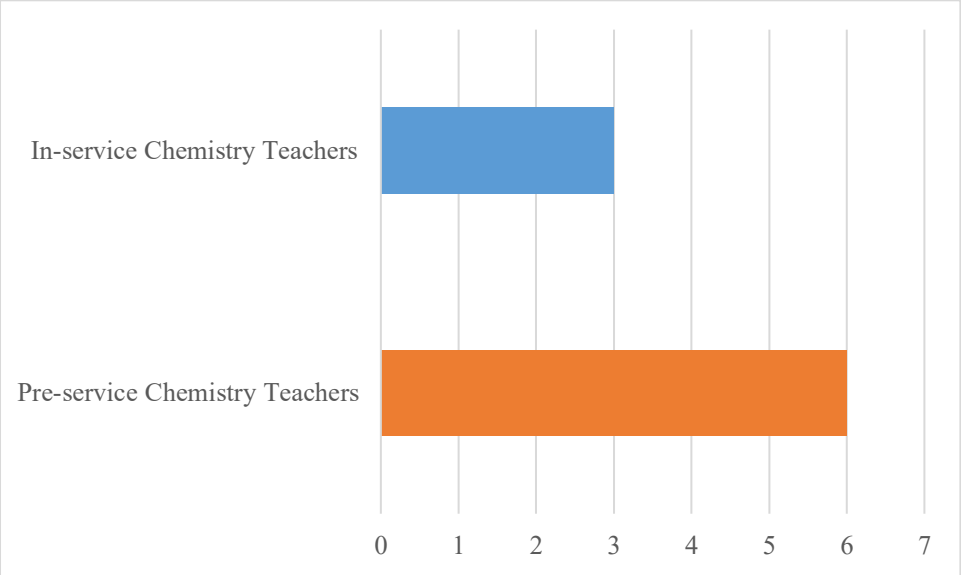

Figure 4.9 *Pre-Service and in-service chemistry teachers' experiences to the use of ai in addressing misconceptions and learning difficulties.*

Participants commonly reported asking AI about popular misconceptions regarding some chemistry topics among pre-service teachers. Merve said:

"I ask what are the misconceptions of this topic. Then I ask how can I do this in class." (Merve, preservice chemistry teacher)

Likewise, Defne said:

"I asked, What are some common misconceptions students have about this topic? I also asked for help so as not to accidentally create a new misconception while explaining the concept." (Defne, preservice chemistry teacher)

Some of the participants used AI as a source of information about the conceptual difficulties reported in the literature. Emre explained:

"We looked into common myths in literature. "It helped us identify which misconceptions were commonly reported and how they could be addressed." (Emre, preservice chemistry teacher)

In-service chemistry teachers seemed to have more limited use of AI for misconception-related purposes. However, some participants reported using AI to help students understand or clarify confusing ideas. Aslı said:

"If a student isn't understanding something, I sometimes ask AI how I can present it to that student differently," (Aslı , chemistry teacher)

Similarly, Ahmet spoke of consulting AI when students were conceptually confused:

"How can I help students get out of confusion when they are confused about a concept." (Ahmet, in-service chemistry teacher)

Özlem also said AI-generated visuals could help fix misperceptions:

"Visuals created by AI helped me when I was trying to correct misperceptions. "Sometimes visual representations help students to understand the concept better." (Özlem, in-service chemistry teacher)

In general, those participants who used AI for this purpose described it as a supplement to the process of identifying misconceptions, generating alternative explanations, and developing conceptual understanding. However, such uses were less frequently reported than lesson planning, assessment and material preparation activities.

4.2.2 Experienced Benefits of AI Use

Experienced benefits of AI use is the another category can be divided into sub-categories, namely Support for Instructional Planning and Design, Support for Teachers' Own Learning ,and Support for Effective Concept Explanation.

4.2.2.1 Support for Instructional Planning and Design

Participants frequently mentioned AI-based tools as helpful resources for lesson planning and instructional development. Almost all pre-service and in-service

chemistry teachers, eight and nine chemistry teachers respectively, reported that they used AI tools to organise lesson content, generate instructional ideas, design activities, prepare projects, and develop teaching materials. Participants generally saw AI as a helpful tool rather than a substitute for their own planning processes, providing suggestions, alternative perspectives, and examples to fit their instructional needs.

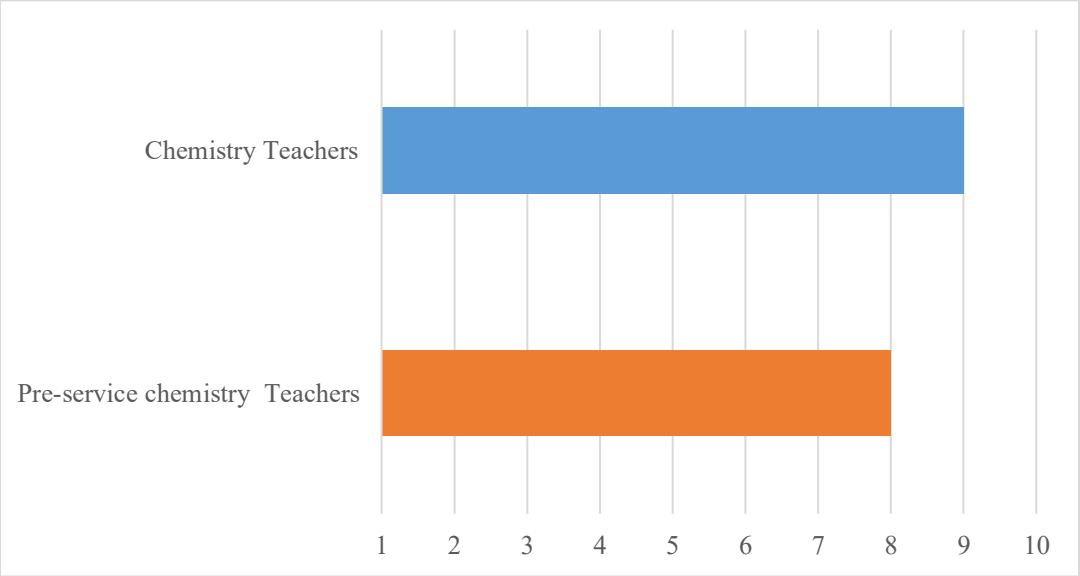

Figure 4.10 *Comparison of pre-service and in-service chemistry teachers' use of ai for lesson planning and instructional development*

Pre-service teachers also often mentioned the benefits of AI-assisted tools in organising lessons and instructional planning. The tools were used by participants for lesson sequencing, choosing appropriate activities, developing teaching materials and gathering ideas for classroom use. Some participants found that the AI-generated recommendations helped them brainstorm ideas that they later adapted for their own teaching goals. Emre explained how AI helped in different stages of lesson planning and gave suggestions for instructional choices:

I ask how I can initiate the lesson, which concepts I should explain, and how I can relate what I taught before to what I will teach next. So this is how I get suggestions for my planning. It helped me in lesson plan preparation, question creation, visuals and even in predicting possible student response. (Emre, preservice chemistry teacher)

Cihan also portrayed AI as a useful provider of instructional suggestions for use in developing lesson plans and classroom activities:

While preparing my lesson, I asked the AI what kind of experiment I could design, and how I could integrate the topic into the 5E model. It had some thoughts. "Some of them reminded me of alternatives I hadn't thought of at that moment, and helped me organise my lesson plan. (Cihan, preservice chemistry teacher)

Similar experiences have been reported by in-service chemistry teachers. Many participants mentioned that AI-based tools are helpful to prepare lesson plans, design activities, organise sequences of instruction, and generate ideas for projects. Overall, teachers reported that they did not use AI-generated outputs directly, but adapted, revised and assessed the suggestions based on their needs in the classroom. When planning instruction, Seda said AI is helpful to generate ideas:

"Like how do I teach a topic or how do I begin a lesson. It gives examples and suggestions. I don't use them myself, but they are good ideas and examples that I can adapt for my own lessons." (Seda, in-service chemistry teacher)

Ahmet also shared with us that he found AI tools helpful to generate lesson plans and instructional activities:

"I created activities using AI and developed lesson plans around the 5E model. I mainly use these plans as a jumping-off point and then adapt them to fit my own classroom needs." (Ahmet, in-service chemistry teacher)

Overall, participants viewed AI-based tools as supportive resources that aided lesson planning and instructional development. AI was often described as useful in providing ideas, examples, and organisational support to be adapted to different instructional contexts instead of replacing teacher decision-making.

4.2.2.2 Support for Teachers' Own Learning

Participants in both groups reported using AI-based tools to assist their own learning of chemistry concepts. Participants reported using AI not only to help them prepare lessons, but also to learn about topics they were not familiar with, to get more explanations, to check their own understanding, and to explore different perspectives on chemistry concepts. AI was often used when participants encountered concepts they did not understand in detail or required further clarification before teaching.

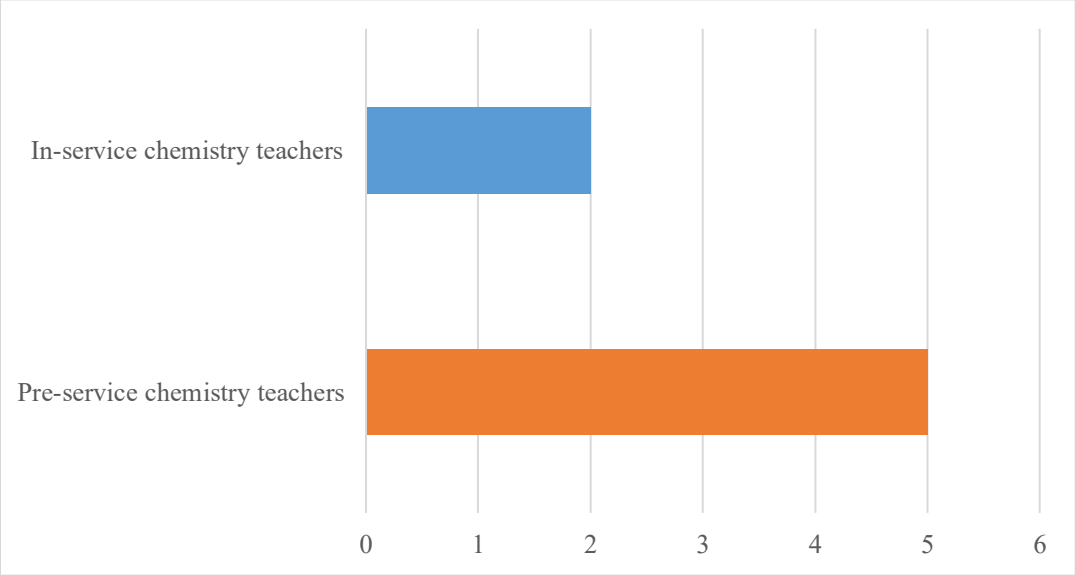

Figure 4.11 *Comparison of pre-service and in-service chemistry teachers who expressed the use of AI-based tools to support their own learning of chemistry concepts.*

Five Pre-service chemistry teachers frequently mentioned AI as a tool to enhance their own comprehension of chemistry concepts. Participants said they used AI when they came across unfamiliar topics, needed more explanations, or wanted to verify their understanding before preparing lessons.

For example, Elif said:

"If I didn't understand something, I would ask AI to explain it. It gave explanations from different viewpoints, which helped me to understand the concept better. (Elif – pre-service teacher of chemistry)

Ece also stated:

> *Method 2 has a lot of stages and I had problems to understand them. I requested AI to repeat all the stages. It was so helpful to first learn about the topic and then my partner and I were able to adapt what we learnt by using Google Scholar and other academic sources. (Ece, pre-service chemistry teacher)*

Two chemistry teachers currently in service also reported similar experiences. Participants reported using AI for elucidation of unfamiliar concepts, to better understand curriculum related content and to validate information before including it in their teaching. As an example, Fatma said:

> *We had a very difficult time understanding some process components because they were expressed in the new curriculum model using different terms. I then used AI to elaborate on these components and describe what was really expected. I didn't use it to make questions or teaching material, I used it just to better understand the content. (Fatma, in-service chemistry teacher)*

And Selin spoke;

"Any time I didn't understand something fully, I would upload images and ask if the information was correct or share my own interpretation. There were many times I went back and forth on these questions with ChatGPT." (Selin, in-service chemistry teacher)

4.2.2.3 Support for Effective Concept Explanation

Participants in both groups reported using AI-based tools to help students better understand chemistry concepts. Participants described using AI to simplify complex chemistry concepts, generate examples and analogies, and visual representations as well as generate explanations appropriate to students' levels of understanding, rather than to improve their own understanding using AI. AI was often employed to convey abstract ideas via alternative teaching strategies that could assist learners in gaining conceptual understanding in chemistry classes.

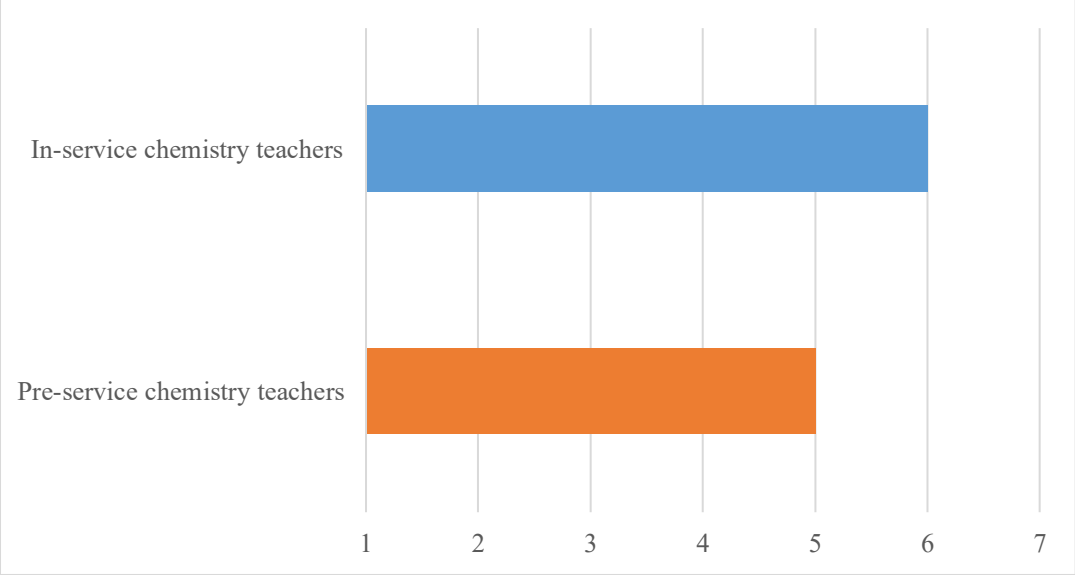

Figure 4.12 *Comparison of pre-service and in-service chemistry teachers who reported using AI-based tools to support effective explanations of chemistry concepts*

The pre-service chemistry teachers reported using AI to adapt chemistry concepts to students' levels of understanding frequently. According to the participants, AI was useful in decomposing complicated ideas, generating examples from daily life, providing alternative explanations, and making abstract chemistry concepts more understandable for students.

For example, Merve said:

"Sometimes I felt my explanation was too difficult for students. So I asked AI to explain it to me at a lower level. "It helped me understand how to make the concept more accessible to students." (Merve, pre-service teacher of chemistry)

Derya also explained:

"For example, in the topic of pressure, AI suggested examples like inflating a balloon, opening a bag of chips, using a syringe. "Such examples from daily life helped me in explaining the concept more clearly to my students. (Derya, pre-service chemistry teacher)

In-service chemistry teachers reported similar experiences. Participants described using AI to produce explanations, analogies, visualisations and instructional examples that were appropriate for students and helped students understand chemistry concepts. For example, Aslı said:

"Sometimes students ask very reasonable questions, but it is difficult to explain concepts at their level. "In such cases AI was very helpful, as it provided different ways of explaining difficult concepts, in the forms that students could understand. (Aslı, in-service chemistry teacher)

Gülşah explained likewise:

"I asked AI to generate examples of analogy for the concept we were discussing. We then went over those examples together and talked about how well they represented the scientific principle." (Gülşah, in-service chemistry teacher)

Mehmet also spoke about using visual materials produced by AI to support conceptual explanations:

"I found AI useful for preparing animations and visual materials, especially for topics such as gases and heat-temperature relationships, as these resources helped explain abstract concepts more effectively." (Mehmet, in-service chemistry teacher)

4.2.3 Experienced Challenges of AI Use

Experienced Challenges of AI Use is the another category can be divided into sub-categories, which are Accuracy and Reliability Concerns, Limitations in AI's Understanding of User Intent, Limitations of Contextual Adaptation and Need for teaching responsible use of AI

4.2.3.1 Accuracy and Reliability Concerns

A common concern among participants was the accuracy and reliability of the outputs produced by AI. Pre-service and in-service chemistry teachers, seven and six respectively, reported instances where AI tools provided wrong information, generated wrong questions, produced wrong explanations, or produced outputs that needed to be verified further. Participants noted that AI-generated responses could not always be taken at face value and often needed to be checked against other sources.

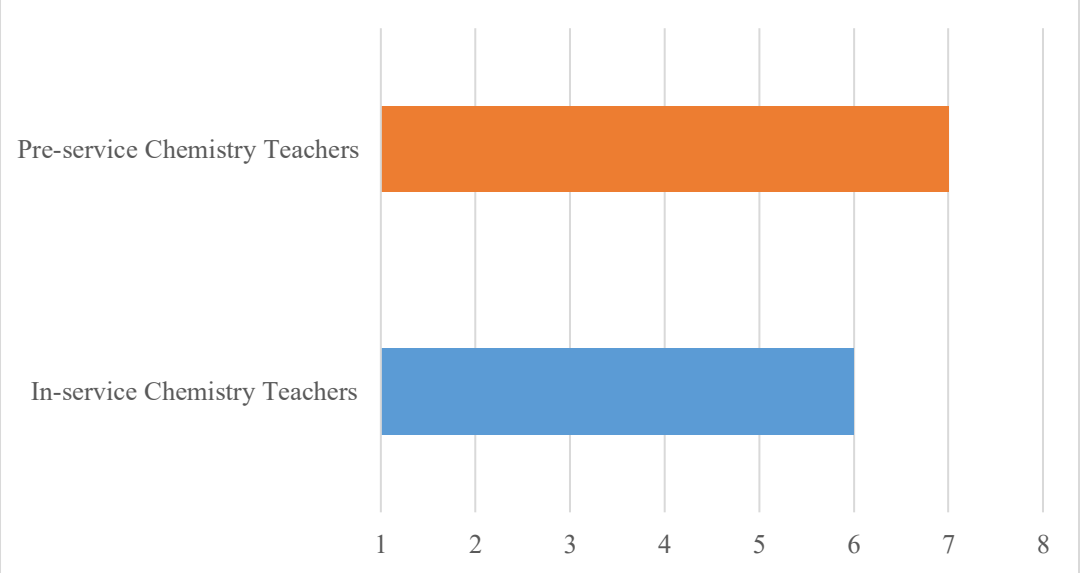

Figure 4.13 *Accuracy and reliability of reporting of pre-service and in-service chemistry teachers ai concerns*

It was common for pre-service teachers using AI-based tools to have incorrect or questionable information. Some participants said AI usually provided useful responses, but they sometimes encountered scientific inaccuracies, inappropriate explanations, or unreliable information. Consequently, participants reported the need to double-check AI-generated content before integrating it into their learning or teaching preparation.

"Sometimes it confirms what I said right away, but then when I do further research, I see that it's not actually correct. There were times when it used the incorrect concepts." (Elif, preservice chemistry teacher)

Likewise, Zeynep reported that AI-generated responses could not always be trusted without further evaluation:

"It doesn't give the right answer one hundred percent of the time. I think the information should definitely be verified with a second source." (Zeynep, preservice chemistry teacher)

Other pre-service teachers also reported concerns about the quality of the generated visuals, accuracy of explanations, and reliability of information provided in response to questions related to chemistry. Such concerns often made participants compare AI-generated outputs with textbooks, academic sources, or other educational materials before using them.

Similarly, in service chemistry teachers reported similar experiences. Participants reported several instances of AI-generated content containing scientific inaccuracies or lack of reliable information. Seda mentioned her experience with the use of AI:

"One time I asked it to create a worksheet. It answered almost every question incorrectly. And it still can't fix them properly even though I've given feedback several times. Finally, I decided to create the worksheet myself." (Seda, in-service chemistry teacher)

Similarly, Fatma said that incorrect answers decreased her trust in information provided by AI:

> *"I could see some of the answers were wrong when I asked questions about things I knew. But when I asked about something I wasn't sure about, I couldn't always tell if the answer was right, which made me feel uncertain." (Fatma, in-service chemistry teacher)*

Moreover, teachers expressed their concerns about poor translations, wrong visual representations, and unreliable content for instructional use. Many participants stressed the importance of checking AI-generated information before using it in classrooms as a result of these interactions.

Overall, pre-service and in-service chemistry teachers identified accuracy and reliability as major issues in the use of AI-based tools. Several participants highlighted the need to critically review AI-generated outputs and crosscheck the information with multiple sources before incorporating it into teaching or learning activities.

4.2.3.2 Limitations in AI's Understanding of User Intent

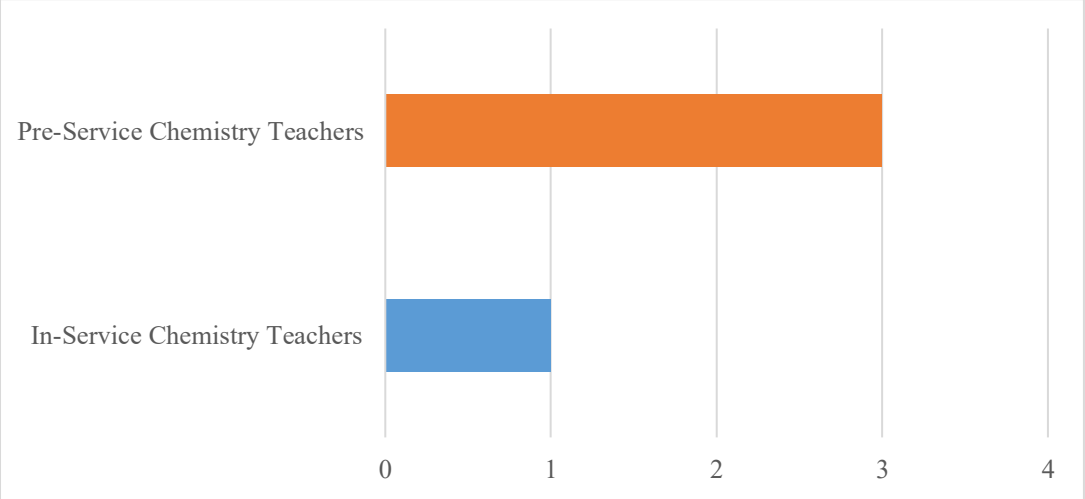

Figure 4.14 *Comparison of pre-service and in-service chemistry teachers report issues with AI understating the user's intentions*

For some users, one of the primary problems was that the AI didn't always understand them or what they were trying to achieve. Three pre-service chemistry teachers and one in-service chemistry teacher reported a problem with what they wanted the AI to produce not being what it actually produced or it was difficult to tell the AI what it was they wanted. The pre-service chemistry teachers in particular had difficulties getting the AI to understand what they were getting them to do.

Defne said she sometimes struggled to get AI to generate a picture for a question for a test. Sometimes she didn't give it a good command, or if she did it didn't understand her, she said.

Sometimes when I'm creating those visuals I don't type the commands correctly or it misinterprets what I'm saying. I am not getting the results I want. (Defne, in-service chemistry teacher,)

Emre also linked his negative experiences to situations where the AI tool did not deliver the desired result. He suspected that perhaps the way he had framed the prompt was responsible for this result:

"I have had bad experiences when I was not able to get what I wanted. Probably when I didn't put the prompt in the right way." (Emre, future chemistry teacher)

Cihan gave a more detailed account of this limitation. "AI can give you alternatives on what it has seen, but it cannot fully understand or come up with the specific idea that I had in my mind," he said.

> *It doesn't fully help me implement something in my mind in the way I want right now. It doesn't quite get what I want. I can't tell it what's in my head. Artificial intelligence does not understand it, for example, I can explain it to you now. (Cihan, prospective chemistry teacher)*

Similar difficulty was also expressed by Meltem, the only in-service chemistry teacher whose response directly reflected this sub-category. She said that when it came to using AI to generate a plan or visual, she couldn't always get the exact output she wanted:

"When I make a plan or a visual or a model I might not be able to get exactly the data I wanted." (Çağla, chemistry teacher)

Overall, pre-service chemistry teachers referred to the limitations of AI's understanding of user intent more than in-service chemistry teachers. This was referred to by three pre-service teachers and one in-service teacher.

4.2.3.3 Limitations of Contextual Adaptation

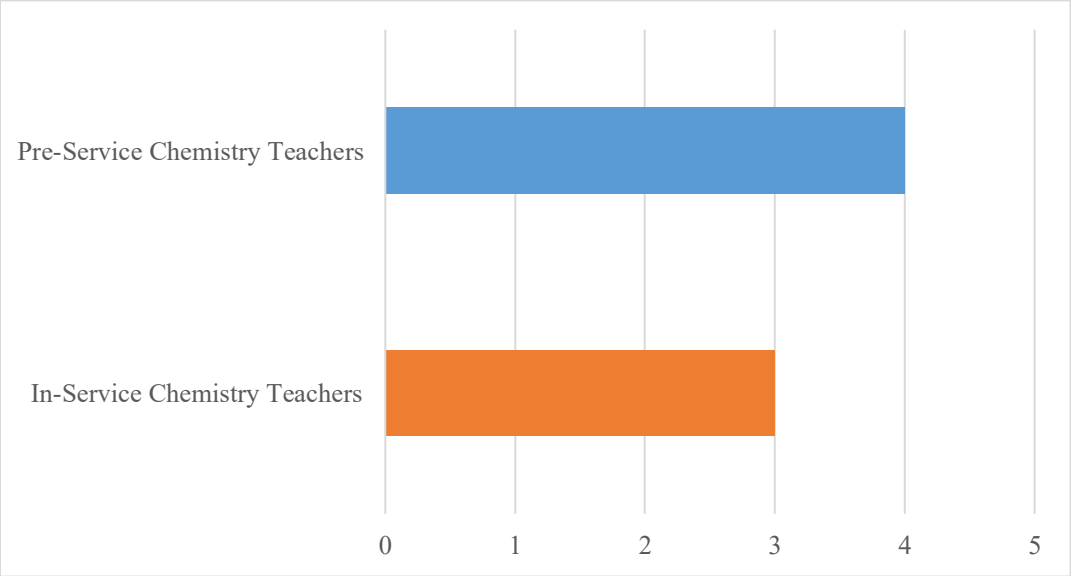

Figure 4.15 *Comparison pre-service and in-service chemistry teachers reporting limitations in the contextual adaptation of AI-generated outputs*

Both groups also reported on instances where outputs generated by AI were not a good enough fit for their education context. Rather than using the generated content as is, participants often reported adapting, modifying, or restructuring AI-generated suggestions to fit their own teaching styles, classroom conditions, student characteristics, or instructional objectives. Four pre-service chemistry teachers and three in-service chemistry teachers reported this sub-category.

Cihan said that:

> *While AI could generate alternative ideas, the pre-service chemistry teachers' suggestions often did not match the particular instructional approach he had in mind. Instead of helping him develop his own ideas, the outputs generated were often too generic and needed further adaptation before they could be used. It doesn't help me that much to develop the particular idea I have in mind. It usually gives me options based on other examples. It's limiting me sometimes in that sense, rather than helping me develop new ideas. (Cihan, pre-service chemistry teacher)*

Similarly, Merve said:

> *She used AI mainly as a supportive tool, not necessarily to directly use its outputs. I usually come up with my own ideas for instruction first and then ask AI to help me improve or refine them, she said. The AI could produce explanations and examples, but these were not always appropriate for the teaching context she had in mind and so needed to be adapted before she could use them in her teaching, she said. I've never had an AI write an entire lesson for me. I design it first and then I write, 'This is what I have planned. What could I put to it?' or 'Would this be appropriate?' I use it mostly as a support tool. For example, I say, 'How would you explain this to a student in the 11th grade?' Then I read its explanation. Sometimes it gives very good examples, but sometimes the examples are quite absurd. If it's a good example I still look it up on the internet because it must have come from somewhere in a database. (Merve, pre-service chemistry teacher)*

Similar experiences were shared by in-service chemistry teachers. Ahmet said that while lesson plans generated by AI often assumed an ideal classroom environment,

real classrooms are quite different and vary widely in terms of student characteristics and classroom dynamics. He said that:

> *It was quite obvious that it was generated by artificial intelligence because it assumes a very ideal classroom environment and he thought that AI-generated plans needed to be modified before implementation. But every classroom isn't quite like that. Each classroom, each group of students, is different. So I think that lesson plans should be tailored to each class. (Ahmet, in service chemistry teacher,)*

Gülşah also mentioned about how the outcomes produced by AI were not always in line with the instructional objectives she had set for classroom activities. She designed an assignment in which students would have a meaningful conversation with ChatGPT, but the first conversation generated by the AI did not support the intended learning outcome. So she reworked the prompts to make it more appropriate for the educational context.

> *When we first assigned the task, we realised that students were not bringing controversial topics and the dialogue with ChatGPT was not developing as a real discussion. As a result, we rephrased the prompts to allow students to have a more meaningful conversation with the AI. (Gülşah, in-service Chemistry instructor)*

Gülşah also said that:

> *The AI-generated lab procedures were not always relevant for the specific experiments her students planned to conduct. Some AI tools generate good procedures for well-known experiments, but for experiments like ours, they didn't generate a proper procedure. It was certainly not a course of action that could be taken. (Gülşah, in-service chemistry teacher)*

Both participant groups reported restrictions related to contextual adaptation. Four pre-service and three in-service chemistry teachers stated that the outputs generated by AI often need to be edited before they can be effectively used in chemistry teaching.

4.2.3.4 Need for teaching responsible use of AI

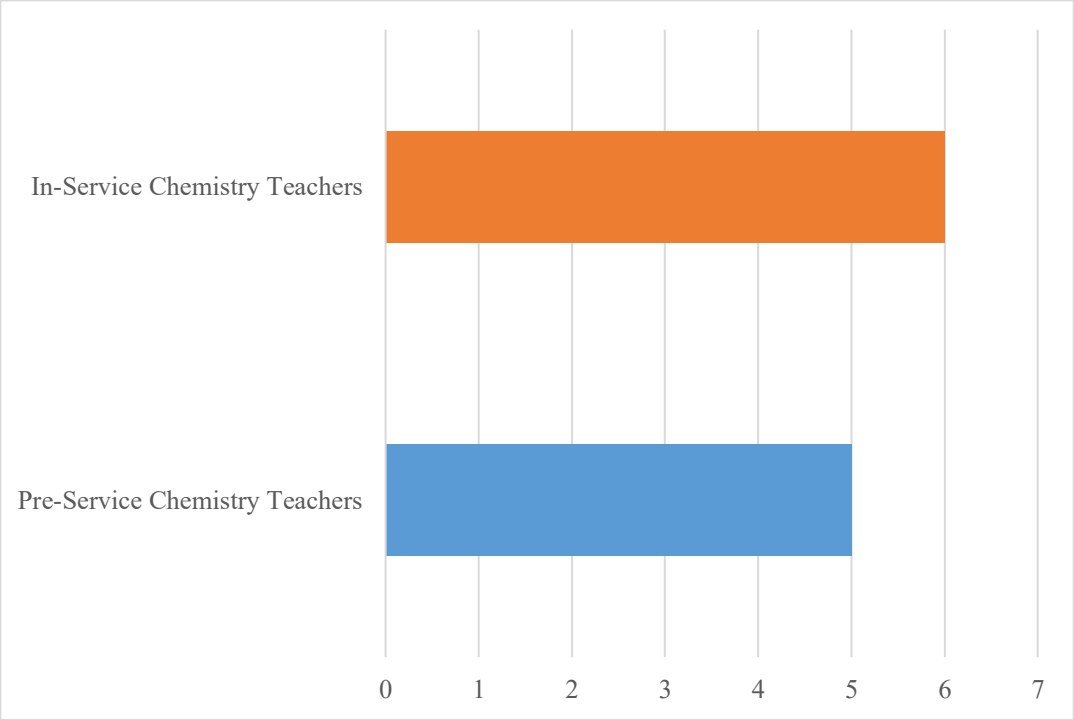

Figure 4.16 *Comparison pre-service and in-service chemistry teachers reporting need for teaching responsible use of AI*

Most teachers, the authors found, emphasised the need to not only have access to AI tools in education but to teach teachers and their students to use and manage them properly. This included discussions around. Teaching the use of AI for both teachers and students and teacher education evaluation and critical thinking when dealing with AI output in lessons Institutional support for the teachers AI Literacies. Five

prospective chemistry teachers, Six chemistry teachers, guidance for the use of AIs in education.

Some of the pre-service chemistry teachers stressed that AI should be used as a learning aid, not as a substitute for independent thinking. They stressed the importance of students knowing how to digest and critique AI-generated content, rather than simply copy and paste, and the necessity of teachers remaining at the heart of the teaching process. She said:

> *I think AI is good for teachers and students. For example, I sometimes upload slides from my university lectures and ask the AI to explain parts that I don't understand. After a few explanations I finally understand the point. So I think it is helpful for students too. But it becomes a problem when students dump all their assignments into AI and submit whatever it spits out without even reading it. I think it can be a good thing for teachers and students if we can get students to use AI and still get the content themselves. Yet, AI should never take the place of the teacher. In the teaching process the teacher must always be the dominant authority. (Merve, Pre-Service Chemistry Teacher)*

Other pre-service teachers emphasised the need for training teachers to use AI effectively.

> *Teachers need to build their own AI competence through professional development opportunities before they start using AI in their classrooms, I think it is okay to use AI in education, but only if we know how to use it properly. Teachers need to learn about AI before they can teach it to students. The betterment of the teachers themselves, for example in the form of courses or formal training, is a matter for their own efforts. Universities or other institutions should also offer courses or opportunities that allow teachers to develop these competencies. (Ece, Prospective Chemistry Teacher)*

Cihan also stressed the need for a systematic approach to teaching teachers and students on the use of AI and suggested that AI literacy be included in the curriculum:

> *We have to teach students how to use AI right. Instead of banning, we need to create assignments and projects that make them use AI appropriately. Since students are already using these tools, teachers should become more knowledgeable about AI and this should gradually become part of the curriculum so that both teachers and students can use it more effectively. (Cihan, Pre-Service Chemistry Teacher)*

The participants also stressed that the responsible use of AI requires teacher training, student awareness and institutional support among the in-service chemistry teachers. Aylin emphasised the significance of enhancing teachers' technological skills, and also teaching students how to use AI correctly:

> *AI needs to be used more broadly in education. Simultaneously, technological skills and possibilities of chemistry teachers should be improved and students should be informed about inappropriate use of AI. If these conditions are provided, AI can support more effective teaching and learning. (Aylin, in-service Chemistry Teacher)*

In this respect, Gülşah argued that responsible AI integration requires broader educational policies rather than the work of individual teachers:

> *If AI is to be used in education, students and teachers both need to be educated about AI. This awareness will come in time. More importantly we need to rethink where education is headed with AI. There are different opinions, so there should be a common direction. I also think that the Ministry of National Education should develop clear policies, not only rely on short online seminars. (Gülşah, in-service chemistry Teacher)*

Özlem also described how AI can be incorporated into learning activities, and at the same time motivate students to critically evaluate the responses generated by AI rather than taking them at face value:

> *We asked students to talk through a topic with ChatGPT, and then identify the parts of its responses that were scientifically wrong. This way, students were using AI, but also learning to identify its limitations and potential dangers, rather than accepting every answer as correct. (Özlem, in-service chemistry teacher)*

4.3 Recommendations for Effective AI Integration in Education

The last theme is divided into three categories after the analysis of the participants' answers, namely; teacher-related, student-related and Institution-related

4.3.1 Teacher-related

This category include only one sub-category, teacher training for AI competence and awareness.

4.3.1.1 Teacher Training for AI Competence and Awareness

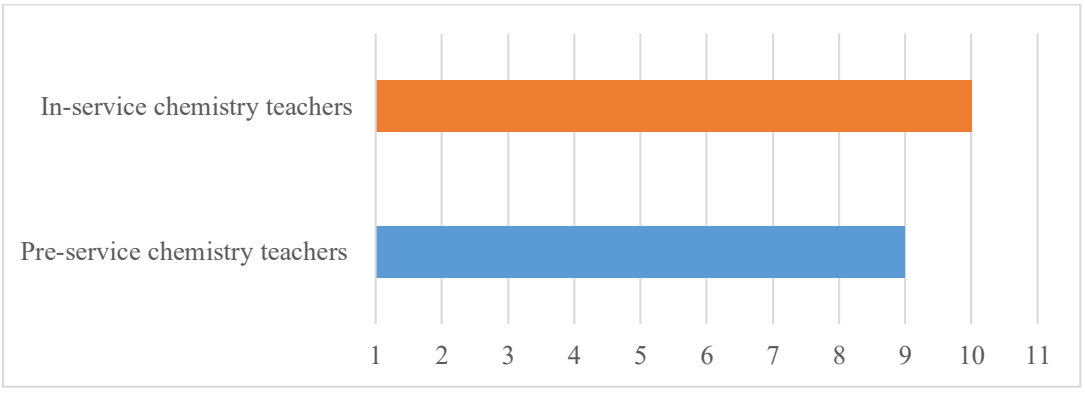

Figure 4.17 *Comparison pre-service and in-service chemistry teachers reporting teacher Training for AI Competence and Awareness*

Participants consistently stressed that successful integration of AI in education depends on improving teachers' knowledge, skills, and confidence in AI. Both pre-service and in-service chemistry teachers stressed the necessity of equipping teachers with the necessary competencies to utilise AI efficiently in educational settings. Participants suggested that AI training should include building practical skills like understanding AI's capabilities and limitations, writing effective prompts, selecting suitable tools for instruction, and integrating AI into chemistry teaching, not just introducing AI tools. The analysis of the interviews resulted in the following sub theme: Teacher Training for AI Competence and Awareness

All participants, nine pre-service and ten in-service chemistry teachers emphasised the importance of systematic training of teachers on AI. Pre-service teachers, however, paid more attention to the integration of AI education in the teacher preparation programs at universities, and in-service teachers paid more attention to continuous professional development, discipline-specific training, workshops and hands-on in-service education.

Some pre-service chemistry teachers stated that AI education should be included in teacher education and should be integrated into the university programs. Participants suggested that prospective teachers should first develop a general understanding of AI and then participate in subject-specific training showing how AI can be integrated into chemistry teaching. Elif explained:

> *I think first the general training should be done, regardless of the subject area, and then it should be discipline specific. In particular, training should be provided on the use and integration of AI for subjects such as chemistry, physics and mathematics. I think this would be very helpful. For example, in chemistry education, chemistry teachers could meet in a classroom setting where they act as students and are taught by an instructor. The instructor could provide common misconceptions and show how AI could be used to*

explain them with examples in an interactive environment. (Elif, pre-service chemistry teacher)

Similarly, Cihan pointed out that:

AI education should be integrated into teacher education as a compulsory part. The teachers and the pre-service teachers need to be trained on how to use technology and AI. AI education should start at university and be a core part of teacher education curricula. (Cihan, pre-service chemistry teacher)

In a similar vein, some practicing chemistry teachers stressed that professional development opportunities should be designed for practical implementation and not for theoretical presentations. The participants proposed workshops, practical training sessions and subject-specific examples of how AI could be integrated into the teaching of chemistry. Fatma said:

"Taining should certainly be given and it should be practical rather than just seminars." (Fatma, in-service chemistry teacher)

Like that, Selin underlined the importance of practical examples in the teacher training:

"There should be trainings, seminars, real-life examples and demonstrations of how AI can be integrated into lessons."(Selin, in-service chemistry teacher)

4.3.2 Student-related

This category contains only one sub-category, training students for responsible use.

4.3.2.1 Training students for responsible use

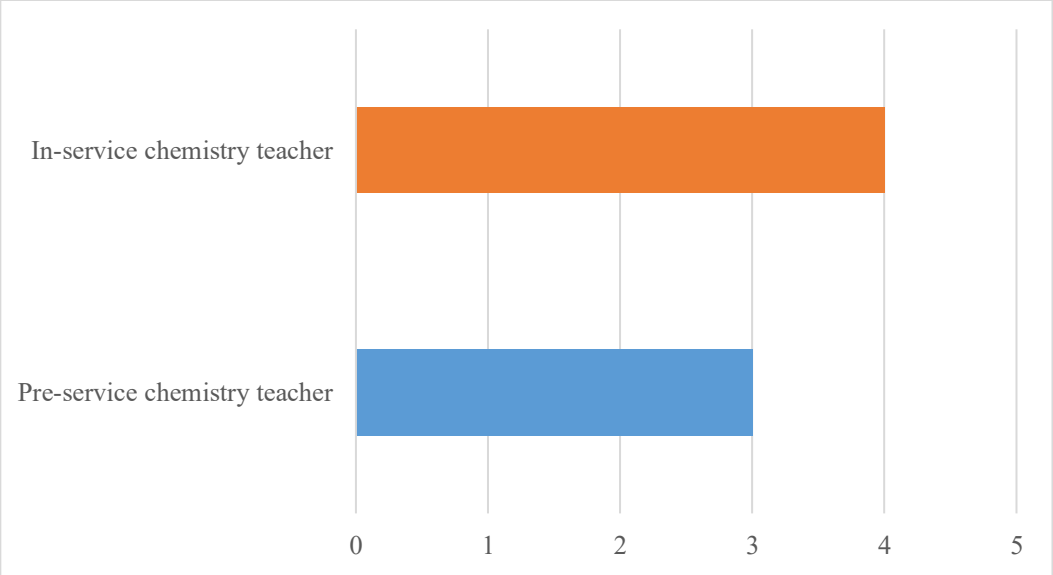

Figure 4.18 *Figuring out of pre-service and in-service chemistry teachers reporting training students for responsible use*

Participants emphasised that the effective incorporation of AI depends not only on the training of teachers on AI competence but also on the responsible use of AI by students. Pre-service and in-service chemistry teachers both suggested guiding students on responsible and critical use of AI instead of forbidding the use of AI. Interviews revealed a sub-theme of coding as training students for responsible use.

The participants of both the two groups collectively emphasised the importance of making students responsible AI users. Pre-service teachers put more emphasis on preparing students to skilfully use AI as an assistant tool such as how to write effective prompts and analyse the information with human expertise. Meanwhile, it is worth noting that in-service teachers paid much attention to warn students of the danger of using AI, mainly including over-reliance, academic cheating and blind trust in AI-generated materials.

For example, Merve explained that a ban on the use of AI would not be an effective solution because students would continue to use it. Instead, she suggested teaching students how to use AI properly:

"Instead of telling students not to use AI, we need to teach them how to use AI properly, how to write good prompts, and how to stay safe when using AI." (Merve, preservice chemistry teacher)

Similarly, Cihan stressed the importance of encouraging students to use AI consciously, and said that responsible AI use should be included in the curriculum:

"Students should be guided to use AI properly. "AI definitely needs to be included in the curriculum to teach students how to use it effectively and responsibly. Also, measures should be taken against misuse." (Cihan, pre-service chemistry teacher)

Similarly, several in-service chemistry teachers pointed out the importance of raising students' awareness of responsible AI use. Fatma pointed out that students need to understand the potential risks of AI before it is fully integrated into education:

"Students need to be much more aware of AI and its possible risks. "They need clear guidance on responsible use."(Fatma, in-service chemistry teacher)

Similarly, Gülşah proposed that schools should advise students on the benefits and dangers of AI at the beginning of the school year, in order to develop responsible habits of AI usage:

"Students should be taught what the risks and benefits of AI are, and how it should be used, at the start of the school year." (Gülşah, in-service chemistry teacher)

4.3.3 Institution-related

This category also contains only one sub-category, establishing institutional conditions for effective AI integration.

4.3.3.1 Establishing Institutional Conditions for Effective AI Integration

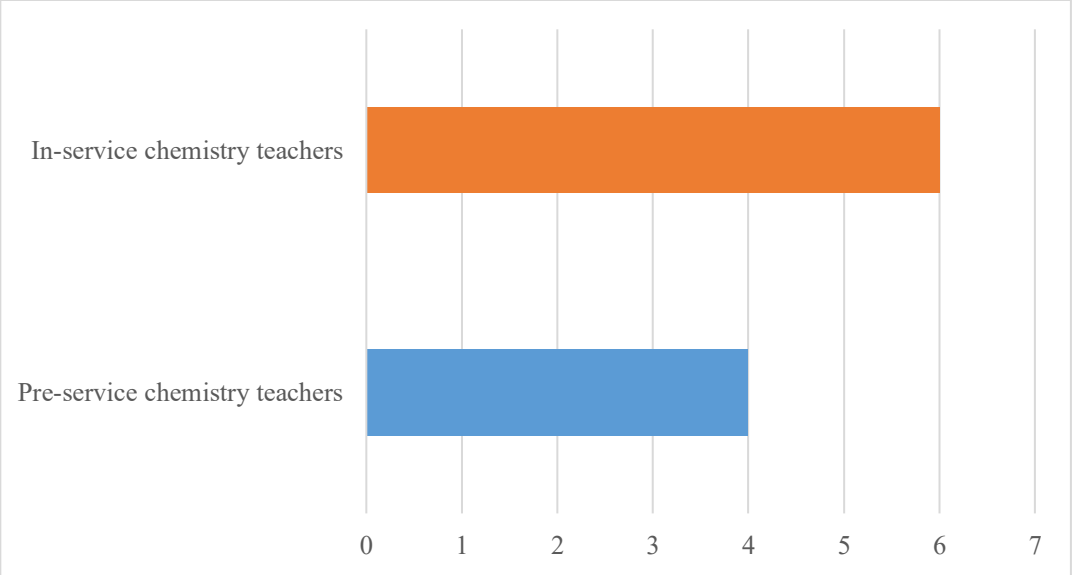

Figure 4.19 *Understanding of pre-service and in-service chemistry teachers recording establishing institutional conditions for effective AI integration*

The participants pointed out that institutionality is necessary for an effective implementation of AI, beyond the efforts of teachers and students themselves. Chemistry teachers, both in-service and pre-service, highlighted the significance of school level institutional policies, curriculum standards and infrastructure for the use of AI technology in education. From the interpretation of interview data of the participants, one sub-theme has been generated, Establishing institutional conditions for effective AI integration.

Both groups mentioned this theme on institutionality. In-service teachers, especially, mentioned on educational policies, internal policies in the scope of schools, implementation and quality assurance on the utilisation process.

Pre-service chemistry teachers discussed this theme mainly in terms of guidance role, incorporation in the curriculum and the infrastructural devices the institutions need to provide their instructors for the productive usage.

Some of the preservice chemistry teachers indicated that institutional regulations and curriculum arrangements should support teachers to integrate AI in chemistry education. Emre stressed that official guidelines could help teachers to be more systematic in their use of AI:

"Educational regulations and inspections could support AI integration. For example, guidelines could specify where and how AI could be used, such as with visualisation." (Emre, preservice chemistry teacher)

Similarly, Cihan argued that AI should become part of the formal curriculum and assessment system gradually:

"AI should be progressively introduced into the curriculum. Assessment methods and assignments should be redesigned accordingly." (Cihan, pre-service chemistry teacher)

In a similar fashion, several in-service chemistry teachers emphasised the significance of institutional policies, standards of implementation and educational infrastructure. Selin pointed out that the right monitoring systems will enable the integration of AI into teaching more successfully:

"There are suitable monitoring systems to oversee the use of AI and then it can be effectively used." (Selin, in-service chemistry teacher)

Likewise, Gülşah underlined the need for schools to have clear policies regarding AI and to set standards for the use of AI in education:

"Schools have to make decisions about AI. "Standards and boundaries of AI use should be clearly defined."(Gülşah, in-service chemistry teacher)

Özlem also stressed that the success of AI integration depends on wider institutional conditions, such as equal educational opportunities, curriculum alignment and teacher support:

"First, equal access to education should be guaranteed. Curricula also need to be tested to see if they actually support AI integration. (Özlem, in-service chemistry teacher)

CHAPTER 5

DISCUSSION

This chapter analyses findings of the study in relation to literature on: the role of artificial intelligence in education; perceptions and experiences of teachers on the use of artificial intelligence; the role of teaching and learning tools related to artificial intelligence in chemistry education. The findings of pre-service and in-service teachers were analyzed and discussed by comparing them to the findings of previous researchers by identifying some converging and diverging aspects between the findings of this study and previous research. The results and their interpretation have been presented. The significance of the results has been discussed. The main conclusions have been drawn.

Some implications for practice are provided with respect to training of chemistry teachers; further professional training; classroom pedagogy and support structure. A section on directions for future research is included in the conclusion.

5.1 Discussion

The present study aimed to explore the opinions and experiences of Turkish pre-service and in-service chemistry teachers about the use of AI-based tools in chemistry education. A basic qualitative research design was used, and semi-structured interviews were conducted with nine pre-service and ten in-service chemistry teachers. The analysis of the interview data yielded three main themes: Teachers' Perceptions Regarding AI in Chemistry Education, Experiences with AI-Based Tools in Chemistry Education, and Recommendations for Effective AI Integration in Education.

In this section the results obtained under these three themes are discussed in relation to the relevant literature. The similarities and differences between pre-service and in-service chemistry teachers are examined in particular, as are the implications of the findings for the integration of AI-based tools in chemistry education. The discussion is structured around the themes and related categories presented in the Results chapter.

5.1.1 Teachers' Perceptions Regarding AI in Chemistry Education

Interviews revealed that pre-service and in-service chemistry teachers mainly considered artificial intelligence as a functional educational technology, not as humanoid or robotic systems. The most common descriptions of AI that participants provided were of digital applications, information-processing systems and technologies that support teaching and learning; few associated AI with robotics or human-like technologies.

This pattern broadly reflects the direction of recent educational AI literature, which has focused on AI applications for teaching and learning rather than its technological characteristics. Almasri et al. (2024) systematically reviewed empirical studies in science education and found that most of the AI research has focused on supporting instructional practices, assessment, and student learning. Likewise, in a systematic mapping review of 407 publications, Yusuf et al. (2024) found that research on generative AI in education has focused on educational applications, users' experiences, and institutional implementation. While these reviews are concerned with the framing of educational AI research rather than teachers' own conceptualizations, they do indicate that there is an increasing framing of AI within educational contexts based on its pedagogical functions and practical applications. This broader trend is reflected in such conceptualizations voiced by participants in this study.

Another interesting observation is the similarities and differences between the two groups of participants. Regardless of teaching experience, there was a shared application-oriented understanding of AI, with the most prevalent conceptualization of AI as digital applications and information-processing systems emerging with strikingly similar frequency among pre-service (n = 6) and in-service chemistry teachers (n = 5). The distinction in the perception of AI as an assistive and facilitative technology became clearer as four in-service chemistry teachers mentioned this, whereas only one pre-service chemistry teacher mentioned this. To date, few studies have directly compared pre-service and in-service teachers' conceptualizations of AI, especially in chemistry education. Hence, this comparison brings in another disciplinary perspective. While both groups shared a similar applied understanding of AI, the in-service chemistry teachers more frequently referred to AI in terms of its supportive and practical role.

Finally, just a few participants related AI with robotics and human-like systems. This finding is consistent with previous studies that have indicated that teachers and teacher candidates may have multiple conceptualizations of AI. For example, Haseski (2019) found that Turkish pre-service teachers had various representations of AI, such as robots and human-like machines. The relatively limited incidence of this perception in the current interview data suggests that anthropomorphic representations of AI still exist among chemistry teachers and pre-service chemistry teachers but are no longer their dominant mode of conceptualizing artificial intelligence.

The interview data revealed that participants had varying degrees of awareness regarding AI-based educational tools. While many participants were aware of generative AI applications like ChatGPT, Gemini, and DeepSeek, some participants reported having limited or no knowledge of AI-specific educational tools. In addition, some pre-service chemistry teachers referred to the use of simulations and animations in relation to AI-based technologies, which indicated some uncertainty about the differentiation of AI and other types of educational technology.

These results suggest that familiarity with readily available generative AI applications does not necessarily translate into a deeper conceptual understanding of AI in educational settings. Long and Magerko (2020) defined AI literacy as a set of competencies that enable individuals to not only use AI technologies, but also to recognize, understand, and critically evaluate them. Their framework consists of competencies on identifying AI, understanding the capabilities and limitations of AI, and differentiating systems with AI from those without. This implies that the association of simulations and animations with AI in the current study could be a matter of differences in the participants' conceptual AI literacy instead of their interest in educational technology.

Sperling et al. (2024) also showed that AI literacy in teacher education cannot be equated with familiarity with digital applications. Their review examined AI literacy in relation to teachers' theoretical knowledge, practical knowledge, and professional and ethical judgement. The authors also pointed out that teachers' professional knowledge has not been fully explored in AI literacy research and stressed the need for teacher training to include how AI functions and how it can be critically and pedagogically incorporated into educational settings. This perspective supports the view that recognizing popular AI applications is only one facet of the knowledge that teachers need to make informed use of AI.

The difference between the two groups of participants was especially remarkable. Only one pre-service chemistry teacher and eight in-service chemistry teachers reported awareness of generative AI tools. On the other hand, the association of AI with simulations and animations was found in six pre-service chemistry teachers and none of the in-service chemistry teachers. However, both groups were represented in limited awareness and no awareness, with one pre-service and one in-service participant in each category. These results should not be taken as evidence that one group was more competent overall in AI, as the participants were not directly assessed on their AI literacy. Instead, the interview responses show that the awareness was articulated differently between the two groups: the in-service chemistry teachers mentioned generative AI applications currently available more

often, while the pre-service chemistry teachers were more likely to associate AI with traditional digital instructional technologies.

In general, AI awareness in education appears to be more than simply recognizing popular applications. The findings, together with the literature on AI literacy, suggest that it is important to develop a conceptual understanding that allows pre-service and in-service teachers to identify AI-based systems, distinguish them from other educational technologies and critically assess their capabilities and limitations, and reflect on their pedagogical relevance. Such knowledge may offer a more robust basis for informed decisions about the integration of AI-based tools into chemistry education.

In terms of perceived benefits, the responses to the interview indicated that pre-service and in-service chemistry teachers mainly perceived AI as a pedagogical resource that could support teaching and learning, rather than as a technological innovation perceived itself. AI was always presented as a tool to prepare lessons, design instructional material, explain difficult chemistry concepts, address misconceptions and make chemistry learning accessible. Such responses suggest that participants assessed AI mostly in terms of the educational value it could add in classroom practice.

This interpretation is consistent with recent trends in chemistry education. Iyamuremye et al. (2024), in their critical review of AI and machine learning applications in chemistry education, concluded that AI has considerable potential to support lesson preparation, concept explanation, personalised learning, intelligent tutoring systems and adaptive instructional practices. The review was not about AI as an emerging technology but about the value of AI for the improvement of teaching and learning processes in the field of chemistry education. This is very much in line with the interview data from the current study, where participants consistently talked about AI in terms of how it could improve teaching practice and support students' conceptual understanding of chemistry.

Another observation from the interview data is that participants rarely referred to AI in terms of its underlying technological characteristics. Rather, they expressed its usefulness in relation to specific instructional practices such as generating examples, reducing complex ideas, preparing learning materials, and providing explanations suitable to students' needs. This finding further reinforces the notion that participants mainly assessed AI on the basis of its contribution to teaching and learning rather than its technical attributes.

Overall, the findings suggest that participants viewed AI as a means to an end, that is, to enhance the teaching and learning of chemistry, rather than as an end in itself. Both groups of participants perceived AI as useful when it helped them with instructional planning, assisted students in understanding chemistry concepts, and enhanced classroom teaching. These findings suggest that the educational value of AI for pre-service and in-service chemistry teachers is associated with its pedagogical usefulness rather than the technology itself.

The literature adds additional support for this interpretation. The use of AI in science and chemistry education has been identified by Erümit and Özdemir Sarıalioğlu (2025) and includes simulations, conversational agents, chemistry problem solving, laboratory-report preparation and assessment-material development. Blonder and Feldman-Maggor (2024) also characterised generative AI as a tool for teachers to produce explanations and instructional resources. In summary, these studies corroborate the current result that participants assessed AI mainly based on concrete pedagogical functions and especially its ability to support representation of abstract chemistry content and generation of subject-specific materials.

One big issue that came out of the interviews was the possible risks of using AI in teaching chemistry. In both groups of participants, there were concerns that reliance on AI could lead to students becoming over-reliant and accepting pre-prepared answers without enough thought or checking, which discourages independent learning. Participants also raised concerns that overreliance on AI could limit students' chances to acquire skills in problem-solving, interpretation, analytical

thinking and critical thinking. They always stressed that its educational value depends on conscious, purposeful and appropriately guided use, and not on an opposition to AI itself.

Such concerns are in line with a systematic review by Zhai et al. (2024) on students' over-reliance on AI dialogue systems. The review demonstrated that students may passively accept AI-generated answers without sufficient questioning or evaluation, and it highlighted the possible consequences of such behaviour for critical thinking, analytical reasoning, and decision-making. But there is an important difference to be appreciated. Although the studies reviewed by Zhai et al. (2024) did provide evidence regarding students' use of AI systems, the participants in the current study perceived these issues as potential educational risks, rather than as experienced outcomes among their own students. Thus, the interview responses demonstrate the professional concerns of teachers about the possible effects of overusing AI, rather than providing direct evidence of diminished student learning outcomes.

The interviews also revealed the ongoing importance of the role of the teacher when AI is integrated into chemistry education. Both pre-service and in-service chemistry teachers stated that AI should help teachers and not replace them. However, this was mentioned significantly more by in-service teachers. In contrast to three pre-service teachers, eight in-service teachers explicitly emphasized teacher guidance, professional judgement and pedagogical responsibility as essential elements of AI-supported instruction. Rather than reflecting fundamentally different attitudes towards AI, the finding suggests that the professional role of the teacher was more salient in the responses of the in-service participants.

A useful point of comparison can be found in Tümen Akyıldız (2026) who reported that pre-service EFL teachers were more likely to construct future-oriented and flexible professional identities with respect to AI, whereas in-service teachers focused more on maintaining their existing professional responsibilities. While that study was conducted in the context of English language education and not in chemistry education, it may provide a relevant perspective to interpret the reasons

why the in-service chemistry teachers in the present study put more weight on teacher guidance and professional responsibility.

The focus on teacher supervision is also consistent with broader guidance on the responsible use of generative AI in education. Miao and Holmes (2023) argued that generative AI should be employed to support teachers, not replace them, emphasizing the importance of meaningful human oversight in educational decision-making. The interview answers support this view very well. Participants did not call for the disapproval of AI integration. Instead, they repeatedly framed teachers as the professionals who should be charged with making instructional decisions, assessing AI-generated content, supervising students' use of AI, and ensuring that AI is used in pedagogically appropriate ways to facilitate meaningful learning.

The literature also aids in explaining why the participants attached such importance to teacher judgement. Blonder and Feldman-Maggor (2024) pointed out that AI-generated explanations of chemistry might contain conceptual errors or misleading representations and thus need to be evaluated by teachers' subject knowledge and pedagogical content knowledge. This point strengthens the interpretation of the present findings, that human oversight is not only a general ethical requirement, but also a disciplinary safeguard against content that might seem plausible while being scientifically or pedagogically inappropriate.

Specific ethical issues were also of concern to participants. The most frequently reported ethical concern was privacy and data protection, with participants cautioning against entering students' personal information, identity, or academic records in AI systems. This result is in line with Miao and Holmes (2023) who found data privacy protection to be an important condition for the responsible use of generative AI in education. Concerns were also voiced about plagiarism, not acknowledging AI-generated material and the unauthorised use or modification of published educational resources. Such concerns mirror Cotton et al.'s (2024) discussion of academic honesty and plagiarism risks with ChatGPT. Finally, the participants' focus on checking erroneous or misleading AI outputs indicates that

content verification was considered not just a pedagogical necessity but also an ethical responsibility. This interpretation aligns with Kasneci et al.'s (2023) emphasis on fact-checking and continued human oversight in the use of large language models for education.

5.1.2 Experiences with AI-Based Tools in Chemistry Education

According to the results of this research, it was found that pre-service and in-service chemistry teachers mainly used AI-supported tools in instructional preparation processes like developing lesson plans, materials and activities and assessment and lesson delivery activities. They did not see AI as a tool to replace decisions about instruction but as a tool to help them in generating and structuring potential teaching ideas. Similarly, Moundridou et al. (2024) identified the potential of generative AI tools to support the preparation of inquiry-based lesson plans, learning activities, instructional content, and assessment tasks. Bower et al. (2024) also found that educators saw AI as potentially useful for pedagogical design, administrative support and some assessment processes. The present findings extend these discussions by showing how pre-service and in-service chemistry teachers incorporated such support into their own instructional preparation.

Importantly, we also found that participants rarely reported using AI-generated outputs without any modification. Teachers in both groups reported reviewing, revising, and adapting lesson plans, questions, activities, and explanations before using them. This indicates that AI generated stuff was used as preliminary stuff, not a finished instructional product. This approach aligns with the human-centred framework proposed by Miao and Holmes (2023) that foregrounds human agency and the pedagogical validation of generative AI applications. In the present study, teachers' iterative assessment and modification of AI outputs show that professional judgement continued to be the primary determinant of whether the generated content was suitable for a specific instructional purpose.

AI was also used to support explanations for teachers' understanding and to generate alternative explanations for chemistry concepts. Although both groups reported these benefits, pre-service teachers referred more often to using AI for their own learning and for identifying possible student misconceptions. Since the present study did not directly investigate the reasons for this difference, it cannot be definitively attributed to participants' level of teaching experience or professional knowledge. However, the finding shows that not all participants were given the same role for AI and that professional stage may be relevant when looking at teachers' experiences with AI. Bower et al. (2024) also observed this contextual variation, reporting that perceptions of generative AI may vary by factors such as teaching experience, discipline, teaching level and AI familiarity. Further research is therefore needed to ascertain whether the differences observed in the present study are consistent across other groups of pre-service and in-service teachers.

Despite the claimed benefits, participants in both groups were cautious about the accuracy of the information produced by AI, its ability to understand specific teaching intentions and the suitability of its responses in context. These challenges help to explain the repeated emphasis by participants on checking and adapting AI outputs. Similarly, Miao and Holmes (2023) argue for the ethical and pedagogical validation of generative AI tools within a human-centred approach, and Bower et al. (2024) emphasize the need to develop teachers' AI knowledge and literacy to make effective changes to teaching and assessment. Based on the current results, it is therefore concluded that mere access to AI tools will not allow a teacher to be integrated into chemistry education and that teachers should additionally have the competencies of evaluation of scientific evidence, evaluation of pedagogical relevance, and adaptation of the content output by an AI tool into the expectations of the intended chemistry course and learning situation of a group of learners.

Research on teachers' direct encounters with AI in general (rather than in a particular subject discipline such as chemistry) also reveals consistent patterns of responses. Wulandari and Purnamaningwulan (2024) reported that novice teachers used tools such as ChatGPT, Copilot, and Quizizz AI during a six-week teacher internship for

preparing brainstorming, material and supplementary resources, designing lesson plans, and creating forms to support assessment. Tripathi et al. (2025) similarly pointed out how K-12 teachers used AI in organising lessons, creating educational teaching materials, helping with explanation within the learning process, and modifying their work performance throughout the time when the technology became part of the daily routine of work of educators.

5.1.3 Recommendations for Effective AI Integration in Education

One of the main findings of this study was the high level of agreement between pre-service and in-service chemistry teachers on the need for systematic teacher training on AI. All 19 participants, nine pre-service and ten in-service chemistry teachers, stressed the importance for teachers to possess the knowledge and skills needed to successfully use AI-based tools in educational settings. However, the two groups differed somewhat in the aspects of training that they emphasized. Pre-service chemistry teachers mainly suggested integrating AI education into university teacher education programs while in-service chemistry teachers emphasized continuous professional development, workshops, hands-on training, and discipline-specific examples. The participants also indicated that such training should not only introduce AI tools but also encompass understanding their capabilities and limitations, formulating effective prompts, selecting appropriate tools, and integrating AI into the teaching of chemistry.

The general demand of teacher training, as pointed out in the present study, is in line with the current attempts of defining the competencies teachers need in AI-supported educational environments. Miao and Cukurova (2024) have developed an AI Competency Framework for Teachers, comprising fifteen competencies in five interconnected dimensions: a human-centered mindset, ethics of AI, foundations and

applications of AI, AI pedagogy, and AI for professional learning. The framework is meant to guide the development of teacher training programs and to support the continuing professional development of teachers at increasingly higher levels. So it makes a case for the participants' belief that teacher preparation should not be just about learning how specific tools work. Rather, they require broader competencies that allow them to comprehend AI, assess its educational implications, employ it responsibly, and make pedagogically informed decisions regarding its integration. This framework is a policy-oriented competency framework and not an empirical investigation and therefore does not, in itself, prove the effectiveness of a specific training program. However, it provides an internationally recognized basis for the interpretation of the range of competencies requested by the participants.

The results are in good agreement with the chemistry-specific needs identified by Yildirim and Akcan (2024). In their qualitative study with 17 chemistry teachers, participants reported a lack of AI literacy, AI competencies and the development of AI-supported lesson plans. The researchers presented a 10-step professional development model for knowledge of AI, AI tools, skills related to AI, ethics, attitudes, literacy, and lesson planning through document analysis, teacher interviews, and analyses of recommendations from AI tools. Crucially, the research also pointed out the importance of domain-specific knowledge and skills and identified areas of organic chemistry, chemical reactions and chemical experiments as potential areas of AI integration. These findings are in very close agreement with the recommendation of the present participants that general AI training should be followed by subject-specific preparation on how AI can be used in chemistry teaching. Hence, the present results appear to reflect, not only a general need for technological training, but also a need that has been documented among practicing chemistry teachers. However, Yildirim and Akcan proposed their model to fulfil the needs they noticed in their study; they did not test whether the participation in the suggested model led to measurable improvements in teachers' competencies or classroom practices.

Emerging research in initial teacher education also supports the pre-service chemistry teachers' recommendation that AI education should be integrated into university teacher education programs. Moorhouse et al. (2024) conducted an 11-week intervention with 54 students on an initial language teacher education program. Their mixed-method findings indicated advancement in all dimensions of the participants' professional competence in generative AI, with particularly noteworthy improvements in pedagogical competence and critical awareness of generative AI use. The study was carried out in language teacher education instead of chemistry education, but it shows that professional AI competence can be taught explicitly and in an organized way within an existing teacher education course. Thus, it supports the plausibility of the present participants' recommendation.

A similar position has been proposed specifically for science teacher preparation. Blonder et al. (2025) argued that generative AI should be incorporated into pre-service science teacher education and suggested that such preparation should include prompt engineering, critical evaluation of AI-generated content, ethics, and opportunities to use generative AI in lesson planning and instructional design. These recommendations are very similar to the competencies mentioned by the participants of the present study, especially prompt formulation, evaluation of AI outputs and the application of AI to discipline-specific lesson planning. However, Blonder et al. (2025) presented a conceptual paper, illustrated by examples from science and chemistry education, rather than an empirical intervention study. The paper can thus serve as a demonstration of conceptual agreement with the present results, but not as empirical evidence that the suggested training content necessarily enhances the competencies of pre-service chemistry teachers.

Research on professional development for science teachers also supports the emphasis placed on practical training by in-service chemistry teachers, rather than mainly theoretical seminars. Nazaretsky et al. (2022) studied a professional development program where K–12 science teachers interacted with an AI-enabled assessment tool and were given explanations of how the system made decisions, how its performance compared with human assessment, and how it could complement

teachers' work. The results showed that explanations about the AI system's operation and its complementary role could decrease teachers' concerns and increase their trust in AI-powered educational technology. The researchers also highlighted the importance of improving teachers' theoretical and practical knowledge of AI through professional development. This supports the current participants' argument that teachers should be provided with opportunities to explore and use AI in meaningful instructional contexts instead of just being given general presentations on AI. But the study investigated one AI-supported assessment tool, not generative AI or chemistry instruction. Thus, its relevance for the present findings is mainly due to its practice-oriented professional development design.

The importance of contextualised support in science education is further evidenced in Park et al. (2023). Their case study involved three secondary science teachers attending an introductory professional development session, implementing an AI-integrated science lesson package and reflecting on their experiences. There were two upper-secondary school chemistry teachers among the participants. Teachers identified a lack of mastery of AI content as a core challenge and called for the provision of clearer and more comprehensive resources to support teachers' understanding of AI. These findings are consistent with the current in-service teachers' emphasis on practical discipline-related support and opportunities to learn how AI can be integrated into lessons. However, the study was based only on three teachers and mainly focused on the integration of AI content into science lessons, rather than explicitly using AI-based tools to support chemistry teaching. This case, therefore, should be viewed as contextually relevant, not as general evidence for all types of AI integration in chemistry education.

The present findings, together with the reviewed literature, suggest the need for a multi-layered approach to teacher preparation for AI integration. Foundational AI knowledge should be linked to, critical evaluation of outputs, prompt design, and discipline-specific applications (Blonder et al., 2025; Miao & Cukurova, 2024; Yildirim & Akcan, 2024). The difference observed between the participant groups also signals the need to provide support at different phases of teachers' professional

development: through structured coursework during initial teacher education, and ongoing, practice-based learning opportunities for in-service teachers (Moorhouse et al., 2024; Nazaretsky et al., 2022; Park et al., 2023). Importantly, the present study establishes chemistry teachers' perceived need for such preparation, not the effectiveness of a particular training model. Future research could thus investigate the long-term effects of intentionally designed chemistry-specific AI training on teachers' competencies, instructional choices and classroom practices.

The finding about training can be further supported by a series of literature connecting AI attitudes with teacher-AI relations and school appropriateness in the classroom context. Furthermore, the perspectives of in-service teachers regarding AI were also associated with their AI knowledge and particular factors such as teaching curriculum, student assessment, and limited time available for instruction (Çayak, 2024). Moreover, Erümit and Özdemir Sarıalioğlu (2025) found that teachers' acceptance was highly dependent on perceived utility, ease of use, and alignment of AI application with pedagogical objectives . They suggested that readiness to use AI could include training in skills and pedagogical support that allows teachers to judge when, how and if the AI tool is appropriate for chemistry learning goals and the classroom context.

The findings of the present study indicated that pre-service and in-service chemistry teachers considered student guidance as an important condition for successful integration of AI into education. The participants were not in favour of banning the AI-based tools but they argued that students should be taught how to use these tools in an appropriate, critical and responsible way. But there was a somewhat different emphasis on the content of such guidance by the two groups. Pre-service chemistry teachers were more concerned with the productive use of AI as an assistive tool, including writing good prompts and judging AI-produced information through human knowledge and judgement. On the other hand, in-service chemistry teachers were more concerned about the possible consequences of inappropriate use, such as over-reliance on AI, academic dishonesty, and uncritical trust in AI-generated content. The results suggest that responsible AI education should encompass both

the practical skills to use AI effectively, and the critical awareness to recognize and manage its limitations.

The participants' preference for guidance rather than prohibition is consistent with findings reported by Johnston et al. (2024). In their survey of 2,555 university students, the participants separate between using generative AI as a limited form of academic assistance and using it to complete an entire assignment. While 54.1% supported or somewhat supported the use of tools for assistance such as grammar checking, 70.4% were opposed or somewhat opposed to using of ChatGPT to write an entire essay. Additionally, 41.1% said there should be a university-wide policy that offers clarity on when generative AI use was and was not appropriate. These findings led Johnston et al. (2024) to conclude that generative AI technologies should not be simply banned, but that students need to have clear and accessible boundaries for acceptable use. Although their research was in higher education rather than secondary chemistry education, this distinction between assistance and substitution closely parallels the views expressed by the participants in the present study. In both cases, responsible use was understood not as not using AI at all but as maintaining the student's intellectual responsibility for the work produced.

This distinction is particularly pertinent to the concerns expressed by the in-service chemistry teachers about academic dishonesty and over-reliance. When students use AI to replace their own thinking, rather than to support it, the educational problem goes beyond plagiarism to include the potential loss of opportunities to practice reasoning, problem-solving and independent knowledge construction. The present findings therefore suggest that students need clear guidance as to which forms of AI support might enhance learning and which forms might disrupt the intended learning process. Similarly, Johnston et al. (2024) discovered that students did not perceive all AI-supported practices to be ethically equivalent: Many accepted limited assistance but rejected the application of AI to create an entire assignment. This supports the participants' argument for clear distinctions between support, collaboration and outsourcing academic work in responsible AI use.

The concerns of in-service teachers about students' blind trust in AI-generated materials are also echoed by Kajiwara and Kawabata (2024). The researchers developed and assessed an AI literacy curriculum aimed at teaching 12 to 24 year-olds the ethical use of large language models. Their results demonstrated that the curriculum was especially beneficial in aiding students' comprehension of LLM concepts and the responsible use of AI in decision-support scenarios. The researchers also found that younger people, especially those aged 12 to 18, were more inclined to accept AI-generated answers when using ChatGPT for decision support. They cautioned that students in lower grades might need more support in interpreting answers created by AI. This finding resonates with the concern raised by the in-service chemistry teachers that students might accept the AI-generated material without proper questioning or verification. This also makes the case for responsible AI education not to be limited to general warnings about risk. Students need structured opportunities to question outputs, to compare them to other sources, to identify possible errors or biases, and to retain responsibility for the final judgement.

This emphasis of pre-service chemistry teachers on prompt writing and evaluation of AI-generated information is also consistent with emerging research on AI literacy instruction. An English for Academic Purposes module included an AI literacy framework that covered AI concepts, how AI systems work, prompt engineering, selection of useful tools and ethical and appropriate use (Ngo & Hastie, 2025). Their mixed-method findings showed that the module improved students' confidence in using AI tools, enhanced students' ability to critically evaluate generative AI outputs, and improved students' confidence in using AI appropriately. The findings suggest that prompt construction and critical evaluation can be taught as academic skills rather than skills students are expected to learn on their own through trial and error. Although the intervention was carried out with international students in a higher education language program, the competencies addressed are very much in line with the recommendations made by the pre-service chemistry teachers in the present study. However, these findings have to be interpreted as indicating the need for

teachers to spend time on the development of the ability to use AI-technology etc. these findings are not evidence that using it leads to a higher quality of teaching in chemistry teachers education secondary-education level teachers.

Woo et al. (2026) provide more specific evidence for prompt instruction. In a mixed-methods study, 27 undergraduate students participated in a 100 minute prompt-engineering intervention integrated into a history course. Post-intervention, students showed increased AI self-efficacy, improved understanding of AI concepts, and indications of improvement in their prompt-engineering skill. Woo et al. (2026) claimed that structured prompt instruction is an improvement over students learning to create prompts in a largely intuitive and unsystematic manner. This finding supports the pre-service chemistry teachers' suggestion that students need to be taught explicitly how to construct effective prompts. But good prompting should not be seen just as a way to get better answers. The formulation of prompts in responsible AI education should be related to the ability to evaluate the relevance, accuracy, limitations and educational appropriateness of the output generated.

The participants' recommendation for integrating responsible AI use into the curriculum is also in line with the AI Competency Framework for Students by Miao et al. (2024). The framework was developed to facilitate the integration of AI learning objectives into official school curricula and comprises 12 competencies grouped into four dimensions: human-centred mindset, ethics of AI, AI techniques and applications and AI system design. It is especially focused on preparing students to use AI safely and meaningfully, to apply critical judgement to AI solutions and to understand their responsibilities as users and citizens in an AI-supported society. The framework reinforces the participants' view of systematic addressing of responsible AI use in the curriculum rather than occasional warnings or answers to isolated incidents. However, as a competency framework it offers curricular guidance, not empirical evidence that a particular program will deliver the desired outcomes in students.

The different emphasis of the two groups of participants can be seen as complementary rather than contradictory. In-service chemistry teachers more often discussed what students need to be protected from or warned about. Pre-service chemistry teachers mostly discussed what students need to be able to do with AI. This may reflect their differing views on AI integration, with pre-service teachers tending to approach responsible use through developing practical AI literacy skills, while practicing teachers drew more directly on concerns related to student behaviour, assessment, dependency and classroom accountability. However, the results do not demonstrate that these orientations are innate characteristics of all pre-service and in-service teachers. They are patterns found among the participants in this qualitative study and therefore should be understood within the bounds of the sample.

The present results, together with the literature reviewed, indicate that training students in the responsible use of AI must include several interconnected dimensions. Students should be aware of the limits of AI assistance, write effective prompts, evaluate critically the outputs generated, cross-check information, understand the ethical and academic-integrity implications and take responsibility for their own decisions and work (Johnston et al., 2024; Kajiwara & Kawabata, 2024; Miao et al., 2024; Ngo & Hastie, 2025; Woo et al., 2026). In chemistry education, these competencies may be particularly important because AI-generated explanations, calculations, representations, and experimental suggestions may seem plausible without being scientifically complete or accurate. The present study does not show that any particular type of student training will prevent misuse or improve chemistry learning. Rather, it reflects chemistry teachers' perception of the need for systematic student preparation as well as teacher training for effective AI integration. Therefore, subsequent investigations could examine the effect of chemistry-specific AI literacy instruction on how well students can evaluate the scientific accuracy of AI, use AI in a way that does not substitute their own reasoning, and the decisions they make when performing chemistry-related learning activities responsibly.

The findings of the present study demonstrated that the effective use of AI in chemistry education was not considered the responsibility of individual teachers and students alone. Four pre-service and six in-service chemistry teachers stressed the need for wider institutional conditions such as school-level policies, curriculum arrangements, technological infrastructure, implementation standards and institutional support. But the two groups emphasized these conditions in slightly different ways. Pre-service chemistry teachers were more worried about formal guidance on where and how to use AI, the progressive integration of AI in the curriculum, and the redesign of assignments and assessment practices. In-service chemistry teachers were more aware of school level policies, well-defined boundaries, institutional monitoring, quality assurance, infrastructure, equitable access, and ongoing support for teachers. These findings suggest that participants' understanding of effective AI integration is that it is an organizational process that requires coordinated pedagogical, technological and governance-related arrangements rather than isolated classroom initiatives.

The focus on institutional support and infrastructure is directly compatible with the chemistry-specific evidence reported by Ahmed and Ibrahim (2026). A quantitative descriptive study was conducted on 207 secondary school chemistry teachers, and participants presented moderate awareness and mostly positive perceptions towards AI-supported chemistry instruction. However the practical use of AI was still limited, particularly for automated assessment, learner monitoring and virtual simulation. The researchers identified AI-oriented pedagogical training, institutional support and educational infrastructure as important conditions for effective and sustainable implementation, based on the gap between positive perceptions and real use in the classroom. This finding is close to the opinion of the present participants that the teachers' willingness or individual competence alone may not be enough if the schools do not offer the necessary resources and organizational support. However, Ahmed and Ibrahim (2026) employed a descriptive survey design; and thus, their study points to an implementation gap and support needs, but doesn't establish a causal link between institutional provision and successful AI integration.

Lara Nieto-Márquez et al. (2026) similarly reemphasize the broader importance of school-level policy and technological capacity. Their research explored the institutional AI readiness of 80 secondary education and vocational training centres in Spain, operationalizing readiness via two interconnected dimensions: institutional policies and technological resources. The results revealed a moderate overall level of readiness, with formal AI policies, dedicated support roles and ongoing teacher training still relatively less developed. This evidence supports the position of the present participants that the implementation of AI should not be up to the discretion of individual teachers. Without clear formal guidance and institutional responsibilities, teachers within the same educational system may make inconsistent decisions about acceptable use, pedagogical integration and management of potential risks. The present findings therefore extend the issue to the field of chemistry education in that chemistry teachers also perceive a need for structures at the school level that can guide and support classroom practice.

The pre-service chemistry teachers' suggestion that institutions should suggest where and how AI can be used is in line with the guidance developed by Miao and Holmes (2023). In their guidance on generative AI in education and research, Miao and Holmes recommended the development of coherent and comprehensive policy frameworks to foster ethical, safe, equitable and meaningful use of generative AI in education. They also stressed ethical validation, pedagogical design, data protection and human responsibility when educational institutions select and use AI tools. These recommendations are in line with participants' desire for formal guidance rather than leaving teachers and students to determine what practices are appropriate. But Miao and Holmes's work is an international policy guide, not an empirical assessment of school-level implementation. It thus offers a framework within which the participants' recommendations can be understood but does not show that any one policy model will inevitably lead to successful outcomes in chemistry classrooms.

The findings on curriculum and assessment are also important. A few pre-service chemistry teachers said that AI should be gradually introduced into the formal curriculum and that assignments and assessment practices should be reconsidered accordingly. Similarly, Chan (2023) proposed a three-dimensional AI education policy framework consisting of pedagogical, governance and operational. The pedagogical dimension includes teaching, learning and assessment. The governance dimension includes privacy, security and accountability. Other elements that come under the heading of 'operationalization' are infrastructure and training. However the model presented in diagram has similarities with the outcomes of the current research project wherein that curriculum and assessment methods, structural rules at the institutional level, the state of infrastructure and teachers' training were reported as complementary needs. The use of AI, either permitted or banned, without revisiting the desired learning outcomes and assessment design might result in ambiguous expectations for teachers and students. But Chan's research was in higher education with university students, teachers and staff. Hence, it should be applied as a conceptual and organizational comparison, instead of being a direct evidence on secondary chemistry education.

However, the emphasis on monitoring and quality assurance by the in-service chemistry teachers should be taken with a pinch of salt. Their recommendations should not be interpreted as an endorsement for automatic AI-detection systems or constant surveillance of students. The present study, and the literature reviewed here, do not support the reliability of such detection tools. A more defensible interpretation is that institutions should periodically review the AI tools being used, check whether existing policies are being followed, examine their pedagogical and ethical consequences, and retain human accountability for educational decisions. Similarly, Miao & Holmes (2023) highlighted ethical validation, human agency and human-centred oversight, while Chan (2023) placed accountability within the governance dimension of institutional AI policy. Thus, institutional monitoring can be understood as an ongoing process of review and accountability, rather than simply the detection of unauthorized student use.

Research on institutional readiness also adds support to the concern about equal educational opportunities. Lara Nieto-Márquez et al. (2026) found differences in AI readiness across different types of schools, with public schools showing lower levels of readiness in some areas. Unequal institutional capacity, the researchers warned, could undermine equitable AI adoption, and they called for targeted support. This supports the concern of in-service chemistry teachers that AI integration should not be done without consideration of access, infrastructure, and institutional resources. Similarly, Miao and Holmes (2023) argued that policies related to generative AI in education should foster inclusion and equity, rather than reproducing or magnifying existing educational inequalities. In teaching chemistry, unequal access to the right devices, software, connectivity or institutional support can mean very different opportunities for teachers and students to benefit from AI supported activities. This study does not measure the extent of such inequality, but the participants' recommendations suggest that they viewed equitable access as a responsibility of the institution rather than an issue that could be addressed by individual teachers.

The different emphases of pre-service and in-service chemistry teachers can be seen as complementary. Pre-service teachers mainly referred to institutional integration in terms of formal curriculum, guidance and assessment design, while practicing teachers focused more on the operational conditions in schools, such as policies, monitoring, resources and implementation support. One possible explanation is that the day-to-day experience of school systems that in-service teachers have might make organizational barriers and accountability requirements more visible to them, whilst pre-service teachers might approach AI integration more strongly through the curriculum and teacher education perspectives they are currently engaged with. However, this interpretation is tentative, as the present study did not directly investigate the reasons underlying the differences between the two groups.

Overall, the findings and the literature reviewed suggest the need for institutional readiness to integrate AI to include clear school policies, alignment of curriculum and assessment, adequate technological infrastructure, ongoing support for teachers, ethical and pedagogical scrutiny, and consideration of equitable access (Ahmed &

Ibrahim, 2026; Chan, 2023; Lara Nieto-Márquez et al., 2026; Miao & Holmes, 2023). The evidence from chemistry, in particular, points to the importance of institutional support and infrastructure, while school-level and policy studies illuminate the wider governance conditions under which such support should be organized. In contrast, the present study identifies the perceived institutional needs of the teachers, and not that a particular institutional model enhances the teaching or learning of chemistry. Further work can consider the impact of specific policies, resource arrangements and support systems at the school level on the actual implementation of AI-based tools in the chemistry classroom.

The institutional recommendations are also in line with the wider literature on trustworthy AI in education. Vincent-Lancrin and van der Vlies (2020) argue that unequal access to infrastructure, AI tools and technical support may limit classroom integration, while the lack of clear governance may lead to inconsistent implementation. Similarly, Zawacki-Richter et al. (2019) showed that the introduction of AI should be seen as a pedagogical and organisational issue and not only the existence of technological applications. These perspectives reinforce the participants' perspective that individual teacher competence cannot fully compensate for absent policies, resources and system-level support.

5.2 Conclusion

The purpose of this study was to examine the perceptions, experiences and recommendations of pre-service and in-service chemistry teachers in Turkey about the use of AI-based tools in chemistry education. The results indicate that the participants are interested in AI, practically involved with AI, but also cautious of it. Both groups, albeit with different conceptualizations and levels of awareness, evaluated AI in terms of its potential contribution to teaching and learning chemistry.

Participants frequently linked AI with digital applications and information processing systems. In-service chemistry teachers tended to refer to readily available generative AI tools, while some pre-service chemistry teachers linked AI with

simulations and animations. The finding suggested that knowledge of digital education tools did not always equate to knowledge of how technologies were AI-based. However, in both groups AI was perceived mainly as a supporting resource rather than as a replacement for chemistry teachers.

The participants thought that AI could support instructional preparation, reduce workload, provide ideas and help teachers to offer alternative explanations, examples, visualizations and learning materials. And they raised alarm over the reliance of students on AI, lack of independent thinking, academic dishonesty, privacy and accuracy of AI-generated content. Teacher guidance, professional judgement and pedagogical responsibility were therefore considered to be vital for the appropriate use of AI in chemistry education.

The participants' experiences revealed that the AI-based tools were mostly used for lesson planning and preparation. They were also used to assess and develop questions, experiment, design activities and materials and address misconceptions and learning difficulties. Participants also used AI to explain unfamiliar chemistry content and to develop explanations suitable for students' levels. However, AI generated outputs were often seen as starting points rather than final products of instruction. The participants often adapted, reviewed and customized them based on the goals of the curriculum, the profiles of the students, the classroom situation and their teaching purposes.

Both groups had major issues with accuracy and reliability. Participants reported inaccurate information, inappropriate questions, misleading visuals, insufficient explanations, and outputs that failed to adequately represent their requests or educational contexts. Such experiences demonstrated that the perceived plausibility of AI-generated content did not necessarily ensure its scientific soundness or pedagogical suitability. The educational use of AI still depended on the teachers' ability to evaluate scientific information and adapt the generated outputs to chemistry teaching contexts.

In general, the views of the two groups were compatible, but there were differences in emphasis in some aspects. Pre-service chemistry teachers more often mentioned simulations, misconceptions, their own learning, skills in writing prompts, and the inclusion of AI in university teacher education. In-service chemistry teachers attached greater importance to practical classroom use, teacher responsibility, student dependency, continuous professional development, school policies, infrastructure and monitoring. These differences are not general characteristics of all pre-service and in-service chemistry teachers but patterns in the present sample.

The recommendations made by the participants were indicative of the necessity of joint preparation on the levels of teachers, students and institutions. Teachers were anticipated to be systematically and practically prepared on the specifics of AI in chemistry, including AI's capabilities and limitations, prompting, tool selection, ethical considerations, and instructional integration. Student preparation was linked to critical evaluation, responsible use, academic honesty, data protection and an understanding of the appropriate boundaries of AI assistance. At the institutional level, participants identified clear policies, alignment of curriculum and assessment, technological infrastructure, equitable access, and ongoing support for teachers.

Overall, AI-based tools were useful when they complemented rather than replaced the professional knowledge and instructional decisions of teachers. The findings reveal that effective use in chemistry education is not only dependent upon access to technology, but also scientific validation, contextual adaptation, ethical consciousness, responsible student use and institutional readiness. The integration of AI should thus be interpreted as a pedagogical and organizational process in which the teacher is responsible for the correctness, appropriateness and educational value of AI-supported practices.

5.3 Implications

The current study offers context-specific insights regarding the preparation needed for effective integration of AI-based tools into chemistry education. The findings are especially relevant to chemistry teacher educators, professional development providers, chemistry teachers, school administrators, curriculum developers, and educational policymakers.

As participants showed different levels of AI awareness and some pre-service chemistry teachers had difficulty distinguishing AI-based systems from simulations and other educational technologies, chemistry teacher education programs should first provide a clear conceptual foundation concerning artificial intelligence. However, AI education should not be confined to definitions or demonstrations of popular tools. It should be included in chemistry teaching methods courses through hands-on activities such as lesson plan writing, assessment question writing, experiment and activity writing, misconception writing, and abstract chemistry concept writing. Pre-service teachers should also be required to investigate the scientific accuracy, pedagogical suitability and ethical implications of AI-generated outputs before adapting them for classroom use. Such preparation is usefully provided through the AI Competency Framework for Teachers that includes AI knowledge, ethics, pedagogy, professional learning, and a human-centred approach (Miao & Cukurova, 2024). Similarly, Yildirim and Akcan (2024) emphasised the importance of combining general AI skills with domain knowledge and put forward a professional development model designed for chemistry teachers.

The results also indicate the importance of continuous, practice-oriented professional development of in-service chemistry teachers. Training should not be limited to short theoretical seminars, but should include opportunities to use AI for authentic chemistry teaching tasks. For example, teachers could evaluate AI-generated questions, adjust lesson plans, review suggested laboratory procedures, compare alternative explanations of concepts, and identify scientific mistakes in generated materials. Since the participants have different prior knowledge and experience,

professional development programs should also be organized at different levels. Introductory training could cover basic AI literacy, prompting, privacy and ethical use, while more advanced programs could focus on instructional design, assessment, contextual adaptation and critical evaluation of AI-generated content specific to chemistry. Such training should reinforce the principle that AI can support the work of teachers, but it does not replace their scientific knowledge, pedagogical judgement, or responsibility for classroom decisions.

The results also imply that chemistry teachers need to give students explicit instructions on how to use AI responsibly, rather than just forbidding it. Students need to know how to develop good prompts, verify the information generated by AI, spot wrong or incomplete science explanations, protect personal information, give credit when they use AI, and distinguish between getting assistance and turning in work that is not their own. Chemistry assessment practices may need to be re-examined. Assignments could require students to explain their reasoning, support answers with scientific evidence, identify errors in AI-generated answers, or explain how they evaluated and revised AI-generated content. The AI competency framework for students also emphasizes the development of knowledge, skills, values, ethical judgement and critical understanding needed for responsible engagement with AI (Miao et al., 2024).

Some of the implications that arise from the study are specifically related to school administrators, curriculum developers and the Turkish Ministry of National Education. Concerns about privacy, academic honesty, accuracy, unequal access, infrastructure, and unclear boundaries among participants indicate that the integration of AI should not be left entirely to individual teachers. Schools and educational authorities should produce clear guidance on what constitutes acceptable and unacceptable use of AI, the responsibilities of teachers and students, procedures for protecting personal data, expectations for acknowledgement of AI use and the conditions under which AI generated materials may be used in teaching and assessment. It should also ensure there is appropriate oversight of curriculum, assessment arrangements, teacher training support and of technology infrastructure,

as these would help foster a responsible approach to the introduction of AI technologies. Miao and Holmes (2023) emphasized human oversight, ethical validation, data protection, and equitable access for generative AI in education. Similarly, Chan (2023) showed that institutional AI policy should take into account pedagogical, governance, and operational aspects such as teaching and assessment, privacy and accountability, infrastructure and training.

Overall, the findings suggest that successful integration of AI into chemistry education requires coordinated preparation at the level of the teacher, the student and the institution. Finally, the teacher education and professional development should be practical and chemistry-specific, the student should be prepared to use AI critically and responsibly, and the institutions should provide clear policies, appropriate infrastructure, and equitable support. Since the current study explored participants' perceptions and reported experiences, rather than the effectiveness of a specific program, these implications should be implemented gradually and evaluated in authentic chemistry education settings.

5.4 Suggestions for Further Research

The purpose of this study was to explore the perceptions, experiences, and recommendations of in-service and pre-service chemistry teachers in Turkey about the use of AI-based tools in chemistry education. The findings suggest multiple avenues for future research.

Given the small size and context-specific nature of the study sample, future studies could include larger and more diverse samples of chemistry teachers from public and private schools, from different universities and from different geographical regions. Studies using quantitative or mixed methods may also be conducted to determine whether the differences identified between pre-service and in-service chemistry teachers exist in larger populations.

Since the present study relied on self-reported interview data, future research could combine interviews with classroom observations, document analysis, and examination of AI-generated lesson plans, assessment materials, or teacher–AI interactions. Such methodological triangulation could provide a clearer picture of how chemistry teachers actually evaluate, revise, and integrate AI-generated outputs into practice in the classroom.

Participants stressed the importance of practical and chemistry-specific AI training. Future intervention studies could, therefore, design and evaluate AI education programs for pre-service and in-service chemistry teachers. Such investigations might include teachers' AI literacy, scientific evaluation of AI outputs, prompt-writing skills, instructional planning, ethical awareness, and classroom practices. Also, longitudinal studies could investigate whether such changes endure after the introduction of AI into an authentic educational context by teachers.

Future research can explore the responsible use of AI by students in learning chemistry. Researchers could examine how students judge the correctness of AI-generated chemistry explanations, calculations, representations, and experimental suggestions, and whether chemistry-specific AI literacy instruction helps them use AI without replacing their own reasoning. Finally, future research may investigate the effects of institutional policies, infrastructure, curriculum arrangements and assessment practices on the responsible integration of AI-based tools in chemistry education.

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APPENDICES

A. Interview Questions for Pre-service and In-service Chemistry Teachers

1. Could you provide a brief overview of your teaching background and current position? (In-service chemistry teachers only)
2. How many years have you been teaching? / Which grade are you teaching? (In-service chemistry teachers only)
3. Have you taken any university courses related to educational technologies or artificial intelligence? (Pre-service chemistry teachers only)
4. Have you received any training or attended any courses related to educational technologies or artificial intelligence? (In-service chemistry teachers only)
5. When you hear the term "artificial intelligence" (AI), what is the first thing that comes to mind?
6. What types of AI-based tools do you perceive are presently being implemented in the field of education and chemistry education?
7. How do you perceive the integration of AI applications into teaching, and how does this integration shape your teaching style and professional identity?
8. What is your general perspective on the integration of AI tools into chemistry education, and how do you believe these tools could facilitate student learning in chemistry?
9. Do you believe it is necessary to use AI in chemistry education? In what way? Could you elaborate?
10. What are your expectations for the potential benefits of AI technologies in the field of chemistry education?
11. What are the potential disadvantages of AI technologies in the field of chemistry education?
12. Have you ever employed any AI-based tools in your chemistry instruction or during your teacher training? If so, could you provide a detailed explanation of the process?
13. Have you experienced any positive and negative consequences, concerns, or constraints when employing or considering the use of AI in the field of chemistry education?
14. In terms of assessment (question preparation, assessment activity preparation, homework assignment, project assignment).
15. In terms of identifying and addressing students' difficulties/conceptual misconceptions.
16. In terms of preparing lessons, experiments, and activities.

17. Have you used them in terms of understanding curriculum-related learning outcomes or subject sequencing?
18. Have you used AI-based tools during lessons?
19. Share any final thoughts on your experience with AI in education not previously mentioned.
20. Based on your experience, how can AI be smoothly integrated into education?
21. What are your suggestions for improving teacher training regarding the use of artificial intelligence in education?
22. Do you have ethical issues regarding the use of AI tools in the classroom, including automation, bias, or data privacy?
23. In your opinion, what ethical obligations do educators have when incorporating AI-based tools into their teaching practices?

B. Ethical Permission

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Gönderen : ODTÜ İnsan Araştırmaları Etik Kurulu

İlgi : İnsan Araştırmaları Etik Başvurunuz

Sayın Prof. Dr. Yezdan Boz,
Sayın Cansu Erol,

"Kimya Öğretmenlerinin ve Kimya Öğretmen Adaylarının Yapay Zekanın Entegrasyonuna İlişkin Bakış Açıları / Perspectives of Pre-Service and In-Service Chemistry Teachers on the Integration of AI" başlıklı araştırmanız ODTÜ İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek 0455-ODTÜİAEK-2025 protokol numarası ile onaylanmıştır.

Bilgilerinize sunarım.

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EĞİTİMİN YÜZYILI

Başvuru No: MEB.TT.2025.031500.01

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Adı Soyadı: CANSU EROL

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Araştırmanın Niteliği: Yüksek Lisans Tezi

Araştırmanın Örneklem / Çalışma Grubu: Öğretmen

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