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# Artificial Intelligence in Chemistry Classrooms: Student Perceptions, Learning Outcomes, and Theoretical–Practical Integration

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**Abstract**

This study examines the role of artificial intelligence (AI) applications in enhancing chemistry education at the University of Zawia, Libya, with a focus on student engagement and learning outcomes in both theoretical and practical contexts. Despite the increasing adoption of AI tools in higher education, empirical evidence on their effectiveness across instructional domains remains limited. A mixed-methods approach was employed, with quantitative data collected from 88 undergraduate chemistry students using a structured questionnaire and qualitative insights obtained through semi-structured interviews. The results indicated no statistically significant difference between students' perceptions of AI use in theoretical and practical chemistry learning (ANOVA: $F = 1.76$, $p = 0.186$; t-test: $t = -1.33$, $p = 0.186$), suggesting that AI is perceived as equally supportive in both domains. In theoretical learning, AI contributed to clarifying complex concepts (26.7%), enhancing motivation (20%), and supporting problem-solving (13.3%). In practical settings, 76% of students reported improved understanding of laboratory procedures, 98% emphasized reduced chemical waste or resource limitations, and 13.4% indicated the use of virtual experiments. Additionally, 87% of students reported improved academic performance, 57% noted compensation for missed or weak lectures, and 88% supported the formal integration of AI into chemistry curricula. Qualitative findings showed that effective AI use increased with academic level, underscoring the importance of early and structured training. The study concludes that systematic integration of AI tools into chemistry curricula, supported by targeted workshops and guided instructional use, can enhance conceptual understanding, laboratory competence, and overall academic performance.



## 1. Introduction

In the era of the scientific revolution, technology has become both indispensable and routine for keeping pace with rapid scientific advancements. Within this context, artificial intelligence (AI) and its

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applications have been increasingly incorporated into educational curricula across diverse institutions. As one of the most innovative instructional strategies, AI not only facilitates the effective delivery of knowledge but also reduces the time and effort required in the teaching–learning process (Husayn et al., 2025; Yahya et al., 2025; Masoud et al., 2025). Moreover, it creates new opportunities to engage students who are more receptive to modern learning methods than to traditional approaches commonly employed in schools and universities (Hasibuan et al., 2025; Alrumayh et al., 2025).

Chemistry, as a central science, underpins a wide range of disciplines, including pharmaceuticals, petrochemicals, environmental science, and sustainable energy. It provides the foundation for understanding natural phenomena, developing innovative materials, and addressing complex societal challenges (Sebayang et al., 2024; Primarni et al., 2025). To fully harness digital technologies in achieving the Sustainable Development Goals, universities must develop adequate infrastructure and implement supportive internal policies (Sulistyowati et al., 2025; Kasheem et al., 2025). By integrating theoretical knowledge with practical laboratory skills, chemistry education equips students with essential competencies in scientific reasoning, problem-solving, and technological innovation. Nevertheless, chemistry learning presents persistent challenges. The abstract nature of chemical concepts, the complexity of curricula, and limited access to effective teaching resources often hinder comprehension. Furthermore, misconceptions in foundational topics and difficulties in linking theory with laboratory practice exacerbate learning barriers. These challenges highlight the urgent need for effective instructional strategies, innovative educational tools, and supportive approaches that foster both conceptual understanding and practical proficiency (Baroud, 2024; Aljarmi et al., 2025).

In chemistry education, the integration of AI plays a vital role in curriculum development, simplifying complex concepts, supporting virtual experimentation, and helping students connect theoretical knowledge with practical applications. Since chemistry comprises both theoretical and practical dimensions, AI has been increasingly applied in both. In theoretical chemistry, AI tools assist in visualizing abstract concepts, modeling molecular structures, and analyzing data. In practical chemistry, AI supports laboratory simulations, experimental design, and real-time analysis, thereby making the learning process more efficient and comprehensive. Virtual laboratories, interactive simulations, and adaptive learning platforms allow students to practice experimental procedures safely, visualize chemical phenomena, and receive immediate feedback. Studies indicate that incorporating virtual laboratories into chemistry lessons significantly enhances student engagement and understanding, particularly among pre-service teachers, by providing opportunities to explore experimental procedures before hands-on practice (Setiawan et al., 2023;

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Alhashem & Alfailakawi, 2023). These tools strengthen the connection between theory and practice while improving efficiency, reducing material consumption, and ensuring safety in handling hazardous substances.

Artificial intelligence has profoundly transformed chemistry education by enabling intelligent, adaptive, and personalized learning experiences. AI-powered tools including Intelligent Tutoring Systems, virtual laboratories, and automated assessment platforms not only enhance conceptual understanding but also improve procedural efficiency. Evidence suggests that integrating AI with innovative pedagogical strategies, such as flipped classrooms, game-based learning, and cooperative approaches like Think–Pair–Share, increases student engagement, motivation, and mastery of complex topics, including hybridization and heterocyclic compound nomenclature (Baroud & Aljarmi, 2025; Kasheem et al., 2025). Furthermore, AI promotes continuous learning by compensating for missed lectures, supporting self-paced study, and offering alternative explanations when conventional resources are insufficient.

AI applications also provide significant advantages in laboratory education through virtual laboratories, adaptive learning platforms, and interactive 3D simulations. These tools enable students to conduct experiments safely and effectively, visualize complex chemical phenomena, and receive personalized feedback, thereby supporting both cognitive and procedural learning (Alhashem & Alfailakawi, 2023; Agbonifo et al., 2020). In the Libyan higher education context, studies at the University of Zawia reveal both opportunities and challenges in adopting AI. Educators and postgraduate students acknowledge its potential for content development, research enhancement, and personalized learning. However, barriers such as limited access to technological tools, insufficient training, and ethical concerns continue to hinder its widespread implementation (Baroud et al., 2024; Elihami et al., 2024; Alsayd et al., 2025). These findings highlight the need for institutional support, targeted professional development, and curricular reforms to maximize the educational benefits of AI integration. By aligning foundational principles with practical realities, an integrated framework can inform future educational initiatives and promote contextually appropriate approaches to teaching and learning in chemistry (Masuwd, 2024).

Moreover, AI-driven tools and digital technologies play a crucial role in bridging the gap between theory and practice in chemistry. By facilitating virtual experimentation, simulating complex reactions, and providing real-time molecular visualizations, AI enables students to connect abstract chemical concepts with practical applications. This integration is vital for developing problem-solving skills, analytical reasoning, and readiness for advanced scientific researchcore competencies in modern chemistry education (Reyes, 2025). Despite the growing adoption of technology and AI in chemistry education, several research

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gaps persist, as many studies address theoretical and practical learning separately without systematically integrating both. Research in the Libyan context also remains limited, with challenges related to resources, training, and ethical considerations (Alouzi, 2024; Abrahem & Baroud, 2025; Ayad et al., 2025).

Against this backdrop, the present study aims to investigate the role of AI applications in supporting students' learning across both the theoretical and practical dimensions of chemistry. Specifically, it examines the relative effectiveness of AI-supported strategies, evaluates their impact on conceptual understanding, laboratory skills, student engagement, and academic performance, and identifies obstacles faced by students and educators in using these tools effectively. By emphasizing the synergy between theoretical knowledge, practical skills, and technological innovation, this study seeks to advance the quality, efficiency, and relevance of chemistry education in today's academic environment while offering evidence-based recommendations for the effective integration of AI into higher education chemistry curricula.

## 2. Materials and Methods

This study involved 88 undergraduate chemistry students from the Faculty of Education at the University of Zawia (Libya), representing all four academic years. **A** purposive sampling technique was adopted to ensure the inclusion of students enrolled in chemistry courses and familiar with AI-supported learning tools. This approach was appropriate for capturing informed perceptions within a specific disciplinary context and for examining differences across academic levels. Data were collected using a structured questionnaire consisting of closed-ended items measured on a four-point Likert scale. The instrument operationalized three constructs: frequency of AI use, purpose of use, and perceived effectiveness of AI in theoretical and practical learning. To complement the survey, semi-structured interviews were conducted with 20 students (five from each academic year), and focus group discussions were held to obtain broader perspectives.

The combination of individual interviews and group discussions allowed for in-depth exploration of personal experiences alongside shared pedagogical and practical insights, thereby strengthening data triangulation. Quantitative data were analyzed using descriptive statistics and inferential tests (one-way ANOVA and independent samples t-test) to compare theoretical and practical learning domains (Michael et al., 2025). Qualitative data from open-ended questionnaire items, interviews, and focus groups were analyzed thematically through a systematic coding process. Credibility was enhanced through data triangulation, peer review of coding, and member checking with selected participants.

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## 3. Results and Discussions

### Quantitative Analysis

This section presents a systematic evaluation of students' perceptions and experiences with AI applications in chemistry education. Descriptive statistics (means, medians, standard deviations, and percentages) summarize general trends, while inferential tests (ANOVA and T-tests) examine differences between theoretical and practical learning domains. The analysis provides a robust foundation for interpreting AI's impact on conceptual understanding, laboratory skills, and academic performance. These findings complement subsequent qualitative insights to offer a comprehensive understanding of AI integration in chemistry education.

**Table 1.**Descriptive Statistics of Students' Perceived Benefits from AI Applications

| Dimension | Mean (M) | Standard Deviation (SD) |
|---|---|---|
| **Theoretical** | 2.64 | 0.84 |
| **Practical** | 2.79 | 0.94 |

This table summarizes the central tendency (mean, median) and variability (standard deviation, range) of students' responses on a four-point Likert scale (1 = Rarely, 4 = Always). The results indicate slightly higher perceived benefits in the practical dimension compared to the theoretical one. As shown in Table 1, the mean score for the practical dimension (M = 2.79, SD = 0.94) was slightly higher than that for the theoretical dimension (M = 2.64, SD = 0.84). The median value was 3 for the practical side, indicating frequent use, while the theoretical side had a median of 2, indicating moderate use.

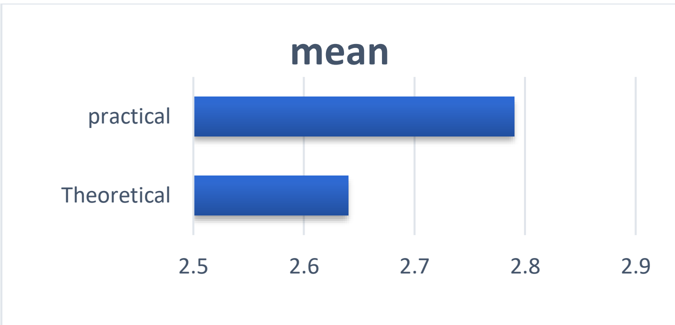


**Figure 1.**The mean score for the practical and theoretical dimensions benefits from AI applications

**Table 2.**Inferential Statistics Comparing Theoretical and Practical Dimensions

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| Test | Test Statistic | p-value |
|---|---|---|
| One-way ANOVA | F = 1.76 | 0.186 |
| Independent T-test | t = -1.33 | 0.186 |

Both ANOVA and T-test results confirm that the difference between theoretical and practical benefits was not statistically significant, despite the mean being slightly higher for the practical side. To test whether these differences were statistically significant, a one-way ANOVA and independent samples T-test were conducted. Results indicated no significant differences between the two dimensions (ANOVA: $F = 1.76$, $p = 0.186$; T-test: $t = -1.33$, $p = 0.186$). This suggests that students perceive AI applications as equally beneficial across both learning contexts.

**Table 3.** Students' Reported Benefits by Category

| Category | Indicator/Statement | Percentage (%) |
|---|---|---|
| **Theoretical Support** | Clarifying concepts with poor explanation | 26.7 |
| | Increasing motivation and engagement | 20.0 |
| | Solving theoretical problems | 13.3 |
| **Practical Enhancement** | Conducting virtual experiments | 13.4 |
| | Understanding laboratory experiments more clearly | 76.0 |
| | Reducing chemical waste / compensating for resource shortages | 98.0 |
| **General Academic Impact** | Improvement in grades after AI usage | 87.0 |
| | AI applications help compensate for missed or weakly delivered lectures | 57.0 |
| **integration Perspective** | Students favor integrating AI tools into official curricula | 88.0 |

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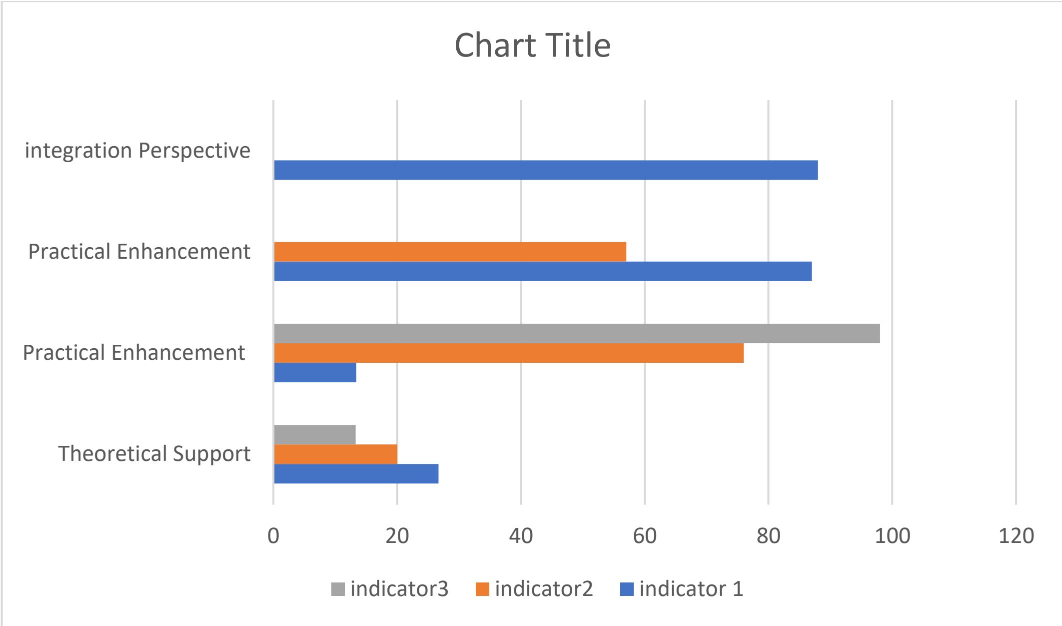


**Figure 2.** Perceived benefits of AI category

Table 3 and Figure 2 categorize the perceived benefits of AI into theoretical, practical, and general academic impacts. The findings indicate that theoretical benefits are primarily associated with conceptual clarity and increased motivation, while practical benefits are closely related to experimentation and laboratory support. In the theoretical domain, AI was most often used to clarify poorly explained concepts (26.7%), enhance motivation and engagement (20%), and support problem-solving in theoretical contexts (13.3%). In the practical domain, the strongest benefits were reported in facilitating a clearer understanding of laboratory experiments (76%) and in reducing chemical waste or compensating for laboratory shortages (98%). Additionally, 13.4% of students reported using AI to conduct virtual experiments. Regarding general academic impact, 87% of students indicated that their grades improved after using AI applications, while 57% reported that AI tools helped compensate for missed or poorly delivered lectures. In terms of curriculum integration, 88% of students expressed support for the formal inclusion of AI applications in chemistry education.

The findings of this study, which revealed that students perceive artificial intelligence (AI) applications as equally beneficial for both theoretical and practical chemistry learning, are consistent with previous research emphasizing AI's dual role in supporting conceptual understanding and laboratory practice. For example, Feldman Maggor et al., (2024) highlighted that AI-based tutoring systems significantly enhance students' comprehension of abstract chemical concepts, while Ali and Ullah (2023) demonstrated that virtual laboratories equipped with task-specific aids (e.g., arrows, audio narration) reduce

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cognitive load and improve students' accuracy and performance in experimental tasks. Similarly, the strong practical benefits reported by students in this study such as reducing chemical waste and clarifying laboratory procedures—align with the findings of Molina-Carmona et al. (2020), who noted that AI-supported simulations provide safer and more resource-efficient alternatives to traditional laboratory work.

Furthermore, the observation that students' AI proficiency increased across academic years supports the notion that sustained exposure and scaffolding are critical for effective technology adoption. This resonates with Duterte (2024) who found that integrating technology-enhanced learning environments can significantly improve student engagement and overall learning outcomes in higher education.. The high percentage of students (88%) supporting the integration of AI tools into the curriculum underscores the urgency of institutional strategies for systematic adoption, echoing calls from Chen et al. (2022) embedding AI literacy as a core component of science education to prepare students for future challenges in STEM fields.

**Qualitative Analysis**

The interviews revealed a clear progression in students' experience with artificial intelligence (AI) applications across academic years. First-year students, particularly female participants, reported limited exposure to these technologies and expressed a strong interest in attending workshops or dedicated lectures to develop their competencies in using AI tools effectively. Several students also highlighted the importance of understanding virtual laboratories, emphasizing their value in comprehending and accurately performing certain chemistry experiments. In order to evaluate students' practical knowledge even more, tests on a range of AI-based applications pertaining to both theoretical ideas and chemistry lab work were given during the interviews. As demonstrated by the average percentage of correct answers in Figure 4, the results showed a definite improvement in performance with increasing academic seniority. According to these findings, even though students usually pick up AI-related skills on their own, structured faculty support is still crucial to ensuring that the use of AI applications is pedagogically aligned and improves learning outcomes. According to the evidence, students' confidence and proficiency could be greatly increased by incorporating focused teaching strategies, such as hands-on workshops and supervised sessions on virtual labs and AI tools. Such an approach would encourage a more methodical and successful adoption of AI in chemistry education in addition to strengthening the link between theoretical knowledge and real-world application.

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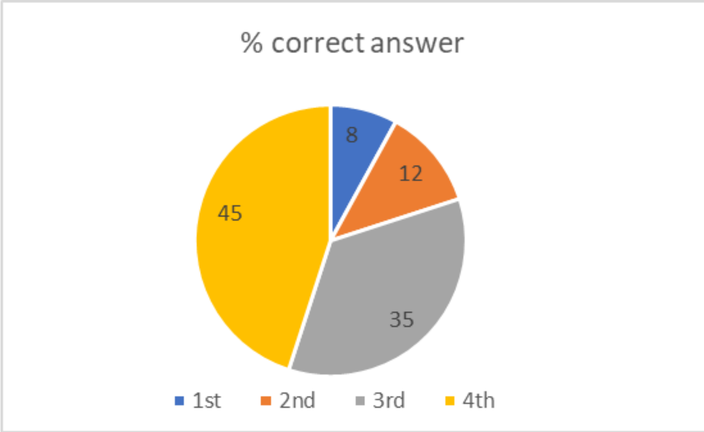


**Figure 3**. The percentage of correct answers for each of the four academic years

These findings underscore the importance of prioritizing the integration of AI applications into the curricula of early undergraduate years. Introducing these tools at the initial stages of higher education would enable first-year students to effectively utilize AI technologies, thereby alleviating common learning challenges and enhancing their conceptual understanding. Early exposure to AI applications not only facilitates learning that is more efficient but also reduces the instructional burden on educators, freeing time and resources that can be redirected toward developing additional skills and competencies. Incorporating AI in the curriculum in a structured and pedagogically sound manner thus represents a strategic approach to fostering student engagement, promoting independent learning, and advancing overall educational outcomes in chemistry education.

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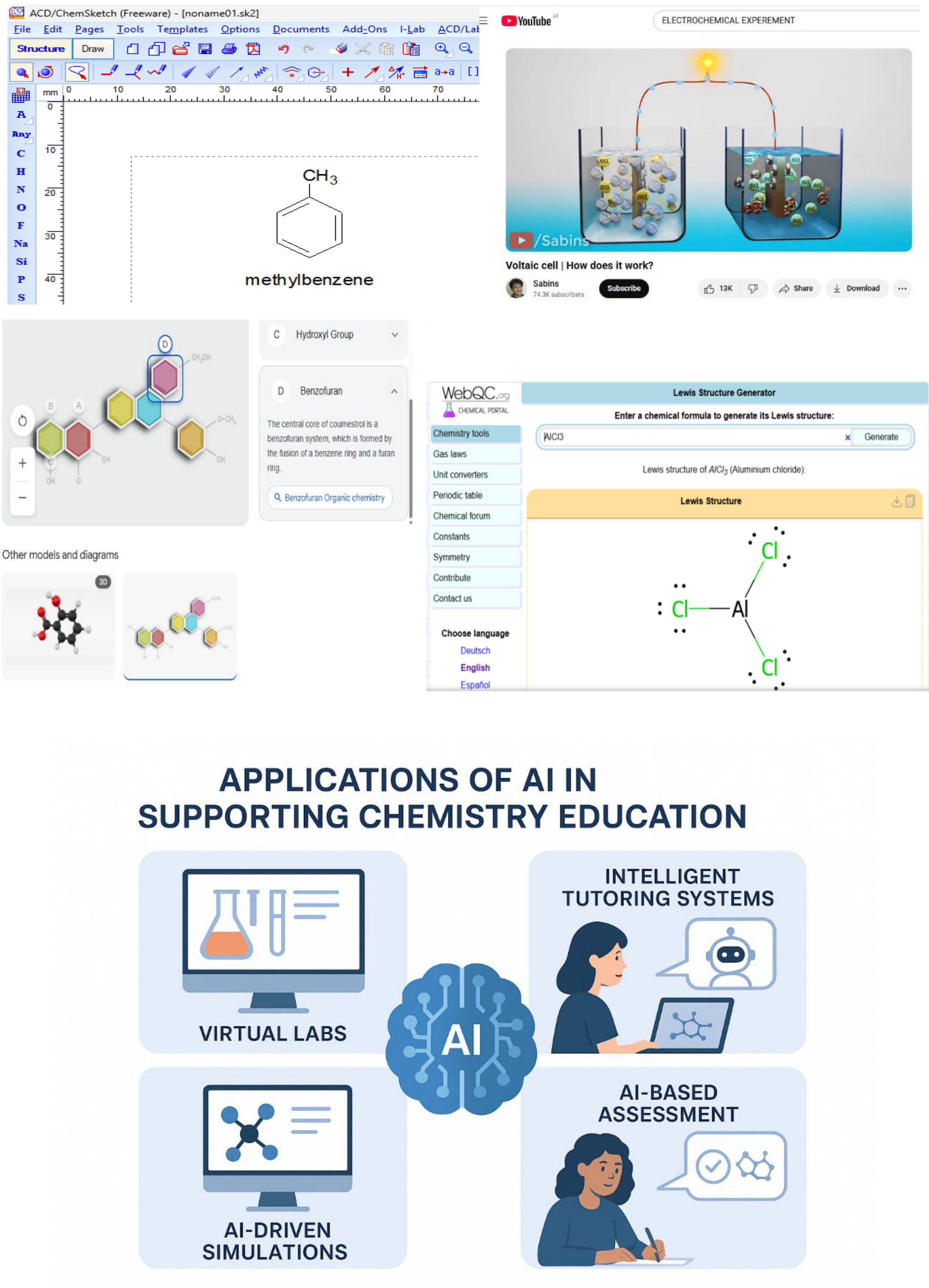


**Figure 4.** The most commonly used applications of artificial intelligence in enhancing chemistry learning

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## 5. Conclusions

This study shows that undergraduate chemistry students at the University of Zawia perceive artificial intelligence (AI) as equally beneficial for both theoretical and practical learning. Although no statistically significant differences were found between the two domains, the findings indicate that AI enhances conceptual understanding, improves laboratory comprehension, increases motivation, and helps reduce chemical waste. The high proportion of students reporting improved academic performance (87%) and supporting formal curriculum integration (88%) highlights the strong potential of AI in chemistry education.These findings suggest that AI can play a meaningful role in addressing both instructional and practical challenges in chemistry teaching, particularly in contexts with limited laboratory resources. The study recommends structured AI training, especially for first-year students, alongside deliberate curriculum integration aligned with course learning outcomes. A key limitation is the reliance on self-reported data from a single institution. Future research should involve multi-institutional samples and longitudinal or experimental designs to better assess the long-term educational impact of AI-supported chemistry instruction.

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The author confirms sole responsibility for all aspects of the study, including design, implementation, data interpretation, and manuscript preparation.

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**Data Availability Statement:** The data that support the findings of this study are available from the corresponding author, Najah Baroud, upon reasonable request. Access to the data is subject to institutional guidelines and ethical considerations to ensure the confidentiality and privacy of study participants.

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